Appendix I

Assessing the Impact of Soil Amendments During the Reclamation of the Proposed Twin Pines Minerals, LLC Saunders Demonstration Mine Using Groundwater Flow Models

Twin Pines Minerals, LLC

ASSESSING THE IMPACT OF SOIL AMENDMENTS DURING THE RECLAMATION OF THE PROPOSED TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE USING GROUNDWATER FLOW MODELS

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EXECUTIVE SUMMARY

This evaluation of the impact of soil amendments on hydraulic conductivity was requested by Georgia's State Geologist, Dr. James L. Kennedy, based on his review of the MODFLOW-2005 numerical model that was prepared to evaluate the impact of the proposed Twin Pines Minerals, LLC mine on the hydrologic system underlying Trail Ridge (Holt et al., 2020). During an August 20, 2020 meeting, Dr. Kennedy expressed the following concerns:

- The humate-cemented, consolidated black sands that generally occur within upper portions of the Surficial Aquifer may be laterally continuous and
- Mining of continuous low-permeability layers might lead to a water table decline in the Surficial Aquifer underlying Trail Ridge, potentially affecting the Trail Ridge groundwater divide that separates the Okefenokee Swamp to the west from the Saint Mary's River drainage to the east of the proposed mine and potentially impacting wetlands within the area of the reclaimed mine.

Based on these concerns, Dr. Kennedy requested that Twin Pines Minerals, LLC (TPM) evaluate whether a soil amendment (bentonite) could be added to the reclaimed sands used to backfill the mine pit to maintain the groundwater divide in the surficial aquifer and support wetlands, *if* consolidated black sands prove to be continuous.

After Dr. Kennedy made this request, the United States Army Corps of Engineers determined the wetlands within the mine footprint are not jurisdictional; therefore, there is no requirement to maintain those wetlands and no current plan to recreate them.

Nonetheless, TPM has agreed to develop a plan to use soil amendments if the consolidated black sands are continuous across the mine footprint. The purpose of this report is: 1) to provide data for designing bentonite soil amendments if they are needed, 2) to illustrate that the position of the water table at the edge of the Okefenokee National Wildlife Refuge is insensitive to the position of the water table in the mine footprint, and 3) to demonstrate that, should soil amendments be required, the groundwater divide along Trail Ridge will be preserved. The information contained in this report can be used to develop a soil amendment plan, if one is required by EPD.

Bench-scale studies were conducted to evaluate methods for decreasing the permeability of post-processed sands returned to the mining pit (Holt et al,2019f). Data obtained from the bench-scale studies were used to construct a linear regression model that allows the hydraulic conductivity for a particular bentonite-sand mixture to be predicted.

For this report, the numerical model of Holt et al. (2020) was modified to include an additional model layer within the upper 10 feet of the original mine footprint. The hydraulic conductivity of this layer was systematically varied to examine the head changes along Trail Ridge and within the mine footprint caused by applying varying percentages of bentonite during sand reclamation. Two modeling scenarios were considered: a Homogeneous Scenario where the horizontal and vertical hydraulic conductivity are constant and equal, and a Layered Scenario where only the vertical hydraulic conductivity is reduced due to the placement of a three-foot thick bentonite-sand layer.

These results can be used to design a soil amendment strategy by defining the percentage of bentonite required to support a given water table position. The model results also show that:

- Water table position in the vicinity of the proposed mine can be controlled by the addition of soil amendments in the upper 10 feet of reclaimed soil.
- Relatively high percentages of bentonite in bentonite-sand mixtures are required to achieve water level increases of 1 to 2 feet over the post-mining scenario of Holt et al. (2020) with no soil amendments (~8% in the Homogeneous Scenario and ~10% in the layered scenario).
- If soil amendments become necessary, a thin (e.g., 3-foot-thick) layer of a bentonite sand mixture is preferred, because it requires less bentonite and allows for a more precise control of the target hydraulic conductivity.
- Altering the hydraulic conductivity within the upper 10 feet of the mined area will have a negligible impact on the water levels of the Okefenokee swamp. Even when water levels are increased to an average of 10.57 feet over the post-mining scenario of Holt et al. (2020) in the mine area (Homogeneous Scenario, hydraulic conductivity of 1E-07), the water level at the Okefenokee National Wildlife Refuge (ONWR) will only decrease by ~0.0001 foot. The original models, which did not include the application of a soil amendments, predicted that the water level at the ONWR would only decrease by ~0.0004 foot. The result of the modified numerical model, and those of Holt et al. (2020), indicate that the water table position in the vicinity of the ONWR is insensitive to the activities in the proposed mine.
- Potentiometric-surface (water-table) maps for the various amendment scenarios modeled in this report show that the groundwater divide beneath Trail Ridge will be preserved, if soil amendments are required. The modeling done here and that of Holt et al. (2020) shows that with or without soil amendments, the groundwater divide is maintained.

The numerical model that Dr. Kennedy reviewed (Holt et. al. (2020)) demonstrated that impacts to ONWR will be negligible. Since that work was completed, the proposed mine area has been reduced from 898 acres to 577 acres by removing acreage closest to ONWR. As a result, mining activity will now be 2.9 miles away from the nearest boundary of ONWR. Because the mine will now be both smaller and further away than previously proposed, potential impacts to the ONWR and the groundwater divide beneath Trial Ridge will be even smaller and more negligible than previously determined.

INTRODUCTION

On March 4, 2020, Twin Pines Minerals, LLC (TPM) submitted a revised individual permit application to the USACE for impacts to water of the United States to develop a heavy mineral sand mine along Trail Ridge in Charlton County, Georgia (Figure 1). This permit application has been withdrawn, and the mine footprint has been revised (Figure 2). The revised mine footprint contains no jurisdictional wetlands. TPM has submitted permit applications for surface mining, groundwater use, and National Pollutant Discharge Elimination System (NPDES) permits to the Environmental Protection Division of the Georgia Department of Natural Resources.

The proposed mine area has been reduced from 898 acres to 577 acres, in part by excluding about 233 acres of property in the western portion of the initial mine footprint. As a result, the distance from the proposed mine to the Okefenokee National Wildlife Refuge (ONWR) boundary is now 2.9 miles at the closest point. Because the mine will now be both smaller and further away, potential impacts to the ONWR and the Surficial Aquifer along Trail Ridge will be even more negligible than previously determined.

TPM proposes a novel approach for mining heavy minerals, which will use a mobile drag line to excavate mineral sands from a small mine pit (maximum size: 500-foot-long, 100 feet wide, and maximum depth of 50 feet). The excavated materials will be moved to onsite processing facilities using a mobile conveyor, where the heavy minerals will be removed from the mined material. About 98% of the mined sand will then be returned to fill and reclaim the inactive portion of the mine pit. The mine pit will advance approximately 100 feet per day. As the drag line advances into unmined areas, the inactive portion of the pit will be filled with processed sand and reclaimed at the same rate as the pit advances.

The proposed mine is located 3.2 miles west of St. George, Georgia, on the north side of Georgia State Highway Route 94. Trail Ridge is a 1 mile-wide and 100-mile-long topographic ridge that separates the Okefenokee Basin and Swamp from the coastal plain of Georgia (Force and Rich, 1989). It represents the crest of a former beach complex and was formed as inland sand dunes near the proposed Twin Pines Minerals, LLC Saunders Demonstration Mine (e.g., Pirkle et al. 1993). The ridge is underlain by a shallow aquifer, locally known as the Surficial Aquifer, which forms a hydrologic divide between the Okefenokee swamplands to the west and the Saint Mary's River to the east. At the proposed mine site, the water table is very shallow with water depths of only a few feet below ground surface. The surficial aquifer is perched on clays of the upper Hawthorn Group, which is considered to be the upper confining unit of the Floridan Aquifer in the region (e.g., Williams and Kuniansky, 2016).

The hydrology and geology of Trail Ridge in the study area has been extensively characterized (e.g., Holt et al., 2019a; 2019b; 2019c; 2019d, 2019e, 2019f, and 2019g). 387 exploratory borings were cored and described by TPM. 217 borings were completed and described by TTL, Inc. (TTL) including 86 piezometers installed in the surficial aquifer. Two deep pumping wells and 22 observation wells were drilled in the northern and southern part of the study area. Soil cores reveal that the upper part of the surficial aquifer is heterogeneous, consisting mainly of unconsolidated sands interspersed with irregular, discontinuous zones of semi-consolidated to consolidated sands cemented by humate. Deeper within the surficial aquifer, below the mining depth, unconsolidated sands are interbedded with discontinuous lenses of clayey sands, silty-clayey sands, and local clay units, likely derived from the underlying Hawthorn Group.

During extensive subsurface field investigations performed within the study are for the proposed mine, the following black humate stained soil layers were identified:

1. black unconsolidated sands,
2. black to dark brown semi-consolidated sands and,
3. consolidated black sands.

These three humate stained soils were depicted on subsurface geologic cross sections presented by Holt et al (2019g); however, the consolidated black sands, which are cemented by humate to create a low permeability layer, are of particular importance for Dr. Kennedy's concerns. The consolidated black sands are easily distinguished from the higher permeability unconsolidated and semi-consolidated black sands layers due to the firm, cemented characteristics of the sand grains (see Photograph 1). Differences in the appearance of the consolidated, semi-consolidated and unconsolidated black sands are shown below:

Photograph 1. Low Permeability Consolidated Black Sand

Photograph 2. Semi-Consolidated Black Sand

Photograph 3. Unconsolidated Black Sand

The subsurface distribution of the consolidated sands may be an important component of local groundwater flow systems in the upper part of the Surficial Aquifer along Trail Ridge. Measurements on two undisturbed consolidated sand samples showed low hydraulic conductivity, 2.7×10^{-8} cm/s and 3.4×10^{-7} cm/s.

Extensive drilling activities performed within and/or immediately adjacent to the proposed permit area indicated that the consolidated black sands are discontinuous in the permit area and appear in irregular zones, not layers (Holt et al., 2019g). Geostatistical studies of the subsurface units present at the TPM site (Holt et al., 2020 and USACE March 4, 2020 permit application) revealed that humate-cemented consolidated sand has a maximum horizontal correlation length of 432 feet, a minimum horizontal correlation length of 240 feet, and a vertical correlation length of 18 feet; these short correlation lengths are consistent with a diagenetic origin for the humate cements.

TPM recognized that closely spaced soils data are not available across portions of the permit area and that soil amendments (e.g., mixtures of sand and bentonite) may be required to maintain higher water levels in the vicinity of wetlands, if wetland restoration were required, and along Trail Ridge. To provide additional data on the continuity of the humate-cemented, consolidated sands, TPM will map the occurrence of consolidated sand during mining operations. If the humate-cemented, consolidated sands are found the be discontinuous across the mine footprint, mapping will cease and soil amendments will not be applied. Should the humate-cemented, consolidated sands be continuous across the mine footprint, TPM is prepared to amend the soils returned to the upper 10 feet of the mine pit to maintain the shallow water table.

TPM previously considered that soil amendments might be required to maintain the water table near wetlands. TPM collected sands from several soil borings at the site and processed the sands using the same approach as proposed for the mine (humate, clays, and heavy minerals were removed). The processed sands were then mixed with varying quantities of bentonite, and the hydraulic conductivity of the resulting mixtures was determined.

The purpose of this report is to use a modeling approach to evaluate the efficacy of soil amendments for maintaining the water table position within the proposed mine and to support the design of soil amendments, should they be required to replace continuous layers of humate-cemented, consolidated sand. This evaluation was requested by Georgia's State Geologist, Dr. James L. Kennedy, based on his review of the MODFLOW-2005 numerical model that was prepared to evaluate the impact of the proposed Twin Pines Minerals, LLC Saunders Demonstration Mine on the hydrologic system underlying Trail Ridge (Holt et al., 2020).

We first develop a model for predicting the hydraulic conductivity of processed sand-bentonite mixtures from the percentage of bentonite added to the mixture. This model is developed from the site-specific data contained in Holt et al. (2019f). We then modify a previously developed, calibrated, steady-state groundwater flow model of the Surficial Aquifer along Trail Ridge (Holt et al., 2020) by including an additional layer to represent the upper ten feet of the reclaimed mine area. The hydraulic conductivity within this layer is systematically reduced to evaluate the change in the water table position due to varying percentages of soil amendments. For this modeling, we consider two scenarios:

1) A uniform mixture of amended soil is placed within the upper ten feet of the reclaimed mine area. In this scenario, the horizontal and vertical hydraulic conductivity are equal.
2) A thin layer of amended soil is placed within the upper ten feet of the reclaimed mine area, and the remaining soil within the upper ten feet contains no amendment. Here, the vertical effective hydraulic conductivity is reduced, while the horizontal hydraulic conductivity is unchanged.

Finally, we discuss the modeling results and the advantages and disadvantages of various possible soil amendment strategies, if required.

SOIL AMENDMENT MODEL

Bench-scale studies were conducted to evaluate methods for decreasing the permeability of sands returned to the mining pit (Holt et al,2019f). TTL drilled 14 soil borings across the study area and collected bulk sand samples from ground surface to 50 feet below ground surface (bgs), which represents the proposed average mining impact depth. The bulk sand samples collected from 0 to 50 feet bgs were drummed by individual boring location and transported to Minerals Technologies, Inc. (MT) in Starke, Florida in order to process the material in a similar manner as the proposed mining extraction process [i.e. extraction of the humate and clays (or slimes) and heavy minerals].

The post-processed sands, minus slimes and heavy minerals, were drummed and then transported to TTL's office in Tuscaloosa, Alabama for hydraulic conductivity (permeability) testing (Holt et al,2019f). The sand samples were placed in a steel chamber that allowed for application of a load equal to approximately 4,500 pounds over 24-hours. Prior to the addition of bentonite, three simulated in-situ samples (UD 338/25 A, B, and C) were collected from the steel chamber using drive tubes for dry bulk density, moisture content, permeability testing. This process was repeated for the permeability testing of sand samples mixed with percentages of bentonite equal to 0.35% and 1.42%, respectively. Additionally, individual samples of sand were collected directly from a drum and mixed with the following percentages of bentonite 5%, 7.5%, 10%, 12.5%, 15%, and 30%. After mixing each sample was remolded and tested for permeability. Bentonite used for testing was a Wyoming bentonite, high yield, high viscosity bentonite produced by Halliburton, Baroid Industrial Drilling Products. Permeability test results are provided in Table 1.

A linear regression model was fit to the log transformed average hydraulic conductivity values shown in Table 1 (Figure 3); note that the lowest value of hydraulic conductivity (30% bentonite, 2.35E-09 cm/s) was excluded from this analysis. The regression has an R^2 value of 0.98 and p-values less than 0.0001. The regression results can be used to predict the hydraulic conductivity of a bentonite-sand mixture:

$$K(pB) = 10^{-3.108-0.3567\,pB} \tag{1}$$

where pB is the percentage of bentonite in the bentonite-sand mixture and K is the hydraulic conductivity in units of cm/s. Equation 1 can be solved for the percentage of bentonite required to yield a particular hydraulic conductivity of a bentonite-sand mixture:

$$pB(K) = \frac{\log(K) + 3.108}{-0.3567} \tag{2}$$

NUMERICAL MODEL OF HOLT ET AL. (2020)

Holt et al. (2020) developed a numerical model to evaluate the impact of the proposed Twin Pines Minerals, LLC Saunders Demonstration Mine on the hydrologic system underlying Trail Ridge. Holt et al. (2020) used MODFLOW-2005 (Harbaugh, 2005) to simulate steady-state groundwater flow in the model domain. MODFLOW-2005 uses an integrated-finite difference formulation to numerically approximate solutions to

$$\frac{\partial}{\partial x}\left(K_h \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v \frac{\partial h}{\partial z}\right) = 0 \tag{3}$$

where h is the hydraulic head; K_h is the horizontal hydraulic conductivity; K_v is the vertical hydraulic conductivity; and x, y, and z are spatial coordinates, given appropriate boundary conditions

For the numerical implementation of MODFLOW-2005, Holt et al. (2020) subdivided the study area into an orthogonal grid of blocks, called cells or grid blocks. In the horizontal plane, the study area was subdivided into 62 rows in the y-direction and 64 columns in the x-direction. Each grid block is ~495 feet wide and ~503 feet long. In the vertical direction, 15 model layers were assigned. Because a deformed model grid was used, model layers vary in thickness from a minimum of 0.1 foot to a maximum of 10.0 feet. The top of the model is the land surface, and the base of the model is the top of the Hawthorn. Additional discussion of the model construction can be found in Holt et al. (2020)

Holt et al. (2020) assigned no flow boundaries to the northern and southern edges of the model domain, constant head boundaries along the western and eastern model boundaries (head values assigned to be at a depth of 1 foot below the land surface along the boundaries), recharge (2.8 in/yr) to the top boundary of the model, and a no-flow boundary to the base of the model due to the low permeability of the underlying Hawthorne. Drain boundary conditions are assigned to the location of the major streams within the model domain. Additional details regarding model boundary conditions and calibration are presented in Holt et al. (2020).

Holt et al. (2020) presented two model scenarios:

1) A Pre-Mining Scenario representing current conditions in the surficial aquifer along Trail Ridge. In this case, the model is calibrated to heads observed in monitoring wells
2) A Post-Mining Scenario in which the hydraulic conductivity within the mine footprint (above an elevation of 119 feet) is homogenized and the vertical and horizontal hydraulic conductivity is set to 1E-03 cm/s. This model was then run using the same boundary conditions as the Pre-Mining Scenario.

Holt et al. (2020) compared the model-predicted heads between the Base Case and Post-Mining Scenarios and found that:

- Trail Ridge is a classic example of topographically-driven groundwater flow.
- Proposed mining activities will have an insignificant impact on the groundwater and stream flow to the Okefenokee Swamp to the west and the creeks and groundwater system to the east of Trail Ridge.
- Mining activities will cause insignificant changes in the water table across the study area.

MODIFIED MODEL

Our current implementation of the model is identical to Post-Mining Scenario of Holt et al. (2020), except an additional model layer was added to represent the upper ten feet of the reclaimed mine area (Figures 4 and 5). The hydraulic conductivity of this layer was systematically varied to examine the head changes along Trail Ridge and within the mine footprint caused by various soil amendments. Two scenarios were considered:

- A Homogeneous Scenario where the vertical and horizontal hydraulic conductivity within the 10-foot thick layer was set to be equal and systematically varied from 1E-04 to 1E-07 cm/s. In this scenario, the upper ten feet within the mine footprint is replaced by a homogeneous bentonite-sand mixture.

- In the Layered Scenario, only the vertical hydraulic conductivity is changed, and it is systematically varied from 1E-04 to 1E-07 cm/s. The vertical hydraulic conductivity is an effective hydraulic conductivity value determined by including a horizontal layer of a bentonite-sand mixture within the 10-foot-thick model layer. Assuming a 3-foot-thick layer of a bentonite-sand mixture, the hydraulic conductivity in cm/s of the 3-foot-thick layer can be determined using

$$K_{layer} = \frac{3.0}{7.0/0.001 - 10/K_{Veff}} \tag{4}$$

where K_{layer} is the hydraulic conductivity of the 3-foot-thick layer of a bentonite-sand mixture and K_{veff} is the effective vertical hydraulic conductivity of the 10-foot-thick model layer. The percentage of bentonite required to achieve K_{layer} can be determined using Equation 2.

RESULTS

The model was run eight times for the Homogeneous Scenario, and the horizontal and vertical hydraulic conductivity of the upper 10 feet in the mine footprint was systematically varied from 1E-04 to 1E-07 cm/s. The average water table rise in the mine footprint due to the addition of bentonite-sand mixtures in the upper 10 feet of the reclaimed soil is presented in Table 2. Soil amendments yielding hydraulic conductivities greater than 1E-06 produced smaller increases in average water levels, less than 1 foot. Soil amendments with hydraulic conductivity less than or equal to 1E-06 led to average water level increases of over 1 foot. Average water levels are most sensitive to hydraulic conductivities bound by 1E-06 and 1E-07 and bentonite contents of ~8% to ~11%. In these ranges, average water levels increase significantly from 1.2 to 10.57 feet.

Potentiometric surface maps showing the modeled water-table position for the Homogeneous Scenario are shown in Figures 6 – 9. These maps show that the groundwater divide beneath Trail Ridge will be maintained regardless of the soil amendments that are applied within the mine footprint.

Contour maps of the difference in the modeled water levels between the Homogeneous Scenario and the Post-Mining Scenario of Holt et al. (2020) are shown in Figures 10 – 13. These figures reveal that decreasing the hydraulic conductivity of the reclaimed soil in the upper 10 feet of the mine footprint would lead to water level rises mainly within the mine footprint. Changes in water levels at the closest boundary of the Okefenokee National Wildlife Refuge (ONWR) are negligible for all soil amendment strategies.

The model was also run eight times for the Layered Scenario; here the vertical hydraulic conductivity of the upper 10 feet of reclaimed soil in the mine was systematically varied between 1E-04 and 1E-07 cm/s, while the horizontal hydraulic conductivity was fixed at 1E-03 cm/s. Table 3 presents the average water level rise within the mine footprint assuming a 3 foot thick layer of bentonite-sand mixture within the upper 10 feet of the reclaimed soil. The percent bentonite in the 3-foot-thick layer ranges from 3.88% to 12.38%. As with the Homogeneous Scenario, average water levels were most sensitive to hydraulic conductivities less than 1E-06 cm/s and bentonite contents of ~10% to ~12%, with average water level increases of ~1.6 feet to greater than 8 feet. It is important to note that water level increases are less sensitive to bentonite content in the Layered Scenario.

Potentiometric surface maps showing the modeled water-table position for the Layered Scenario are shown in Figures 14 – 17. As with the Homogeneous Scenario, these figures demonstrate that the groundwater divide beneath Trail Ridge will be preserved, if soil amendments are required.

Contour maps of the difference in the modeled water levels between the Layered Scenario and the Post-Mining Scenario of Holt et al. (2020) are shown in Figures 18 – 21. As with the Homogeneous Scenario, water level rises due to soil amendments are concentrated within the mine footprint. Water level rises are negligible away from the mined area and at the ONWR boundary.

The hydraulic head difference between each of the Homogeneous and Layered Scenario model runs and the Pre-Mining Scenario of Holt et al. (2020) are shown in Figures 22 – 29. Water levels increase as the hydraulic conductivity of the soil amendments decrease. Changes in water levels due to the soil amendments mainly occur within and adjacent to the mine, and water level changes at the ONWR boundary are insignificant.

DISCUSSION

Should TPM need to develop soil amendments to maintain water levels in the vicinity of the proposed mine, the results of this modeling study can be used to design bentonite-sand soil mixtures. The use of a thin (e.g., 3 foot thick) layer of a bentonite sand mixture is preferred, because it requires less bentonite and allows for a more precise control of the target hydraulic conductivity (as water level increases are less sensitive to changes in bentonite content).

These results can be used to develop soil amendment designs, should a continuous layer of consolidated black sand be encountered in the mine. For example, a predicted water-table decline of

1.6 feet can be prevented by the emplacement of a three-foot thick bentonite-sand layer, containing ~10.27% bentonite, in the upper 10 ft of the reclaimed mine (e.g., Table 3)

The model results presented here also demonstrate that changes in the hydraulic conductivity of the upper ten feet of the mine footprint have an insignificant impact on the water levels at the ONWR. Even when water levels are increased to an average of 10.57 feet (see Table 2 and Figure 13) in the mine area (Homogeneous Scenario, hydraulic conductivity of 1E-07), the water level at the ONWR will only decrease by ~0.0001 foot.

Finally, the groundwater divide beneath Trail Ridge is preserved in all soil amendment scenarios.

SUMMARY

If required for state permits, soil amendments could be utilized during reclamation to maintain the water table position in the vicinity of the proposed mine. In this report, we evaluate the impact of possible soil amendments (bentonite-sand mixtures) on the water-table position using a modeling approach. First, a model for predicting the hydraulic conductivity of processed sand-bentonite mixtures from the percentage of bentonite added to the mixture was developed, and then a previously developed, calibrated, steady-state groundwater flow model of the Surficial Aquifer along Trail Ridge (Holt et al., 2020) was modified by including an additional soil amendment layer to represent the upper ten feet of the reclaimed mine area. The hydraulic conductivity within this layer was systematically reduced to evaluate the change in the water table position due to soil amendments. For this modeling, two scenarios were considered:

1) A Homogeneous Scenario where a uniform mixture of amended soil is placed within the upper ten feet of the reclaimed mine area. In this scenario, the horizontal and vertical hydraulic conductivity are equal.
2) A Layered Scenario where a 3-foot-thick layer of amended soil is placed within the upper ten feet of the reclaimed mine area. Here, the vertical effective hydraulic conductivity is reduced, while the horizontal hydraulic conductivity is unchanged.

The modeling results show that:

- Shallow water table position in the vicinity of the proposed mine can be controlled by the addition of soil amendments in the upper 10 feet of reclaimed soil.
- Relatively high percentages of bentonite in bentonite-sand mixtures are required to achieve water level increases of 1 to 2 feet over the post-mining scenario of Holt et al. (2020) with no soil amendments (~8% in the Homogeneous Scenario and ~10% in the layered scenario).
- If soil amendments were required, a thin (e.g., 3-foot-thick) layer of a bentonite sand mixture is preferred, because it requires less bentonite and allows for a more precise control of the target hydraulic conductivity.
- Altering the hydraulic conductivity within the upper 10 feet of the mined area will have a negligible and insignificant impact on the water levels of the Okefenokee swamp. Even when water levels are increased to an average of 10.57 feet over the post-mining scenario of Holt et al. (2020) in the mine area (Homogeneous Scenario, hydraulic conductivity of 1E-07), the water level at the ONWR will only decrease by ~0.0001 foot. The original models which did not include the application of a soil amendments predicted that the water level at the ONWR would only decrease by ~0.0004 foot. The result of the modified numerical model, and those of Holt

et al. (2020), indicate that the water table position in the vicinity of the ONWR is insensitive to the activities in the proposed mine.

- Our results also demonstrate that groundwater divide that underlies Trail Ridge will be preserved if soil amendments are required. This is consistent with Holt et al. (2020) who demonstrated that the groundwater divide is preserved even if no soil amendments are used during mining reclamation.

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TABLES

Table 1. Average hydraulic conductivity of bentonite sand mixtures reported in Holt et al. (2019f)

Percent Bentonite	Average Hydraulic Conductivity (cm/s)
0	9.73E-04
0.35	8.20E-04
1.42	1.60E-03
5	5.70E-06
7.5	2.00E-06
10	4.90E-07
12.5	1.00E-08
15	5.40E-09
30	2.35E-09

Table 2. Average head rise in the mine footprint for the Homogeneous Scenario. Horizontal and vertical hydraulic conductivity values are equal in the upper 10 feet of the mine. The percentage of bentonite in the bentonite-sand mixture required to achieve the hydraulic conductivity is determined using Equation 2.

Percent Bentonite	Hydraulic Conductivity (cm/s)	Average Head Rise (ft)
2.50	1.00E-04	0.24
5.30	1.00E-05	0.35
6.71	3.16E-06	0.55
8.11	1.00E-06	1.20
8.81	5.62E-07	1.99
9.51	3.16E-07	3.47
10.21	1.78E-07	6.06
10.91	1.00E-07	10.57

Table 3. Average head rise in the mine footprint for the Layered Scenario. Only the vertical hydraulic conductivity in the upper 10 feet of the mine changes in this scenario. The horizontal hydraulic conductivity is the same as that in the Post-Mining Scenario of Holt et al. (2020), 1E-03 cm/s. The percentage of bentonite in the bentonite-sand mixture required to achieve the hydraulic conductivity is determined using Equation 4 and Equation 2, assuming a 3-foot-thick bentonite-sand mixture.

Percent Bentonite	Vertical Hydraulic Conductivity (cm/s)	Average Head Rise (ft)
3.88	1.00E-04	0.01
6.76	1.00E-05	0.08
8.17	3.16E-06	0.55
9.57	1.00E-06	0.87
10.27	5.62E-07	1.60
10.98	3.16E-07	2.94
11.68	1.78E-07	5.21
12.38	1.00E-07	8.87

FIGURES

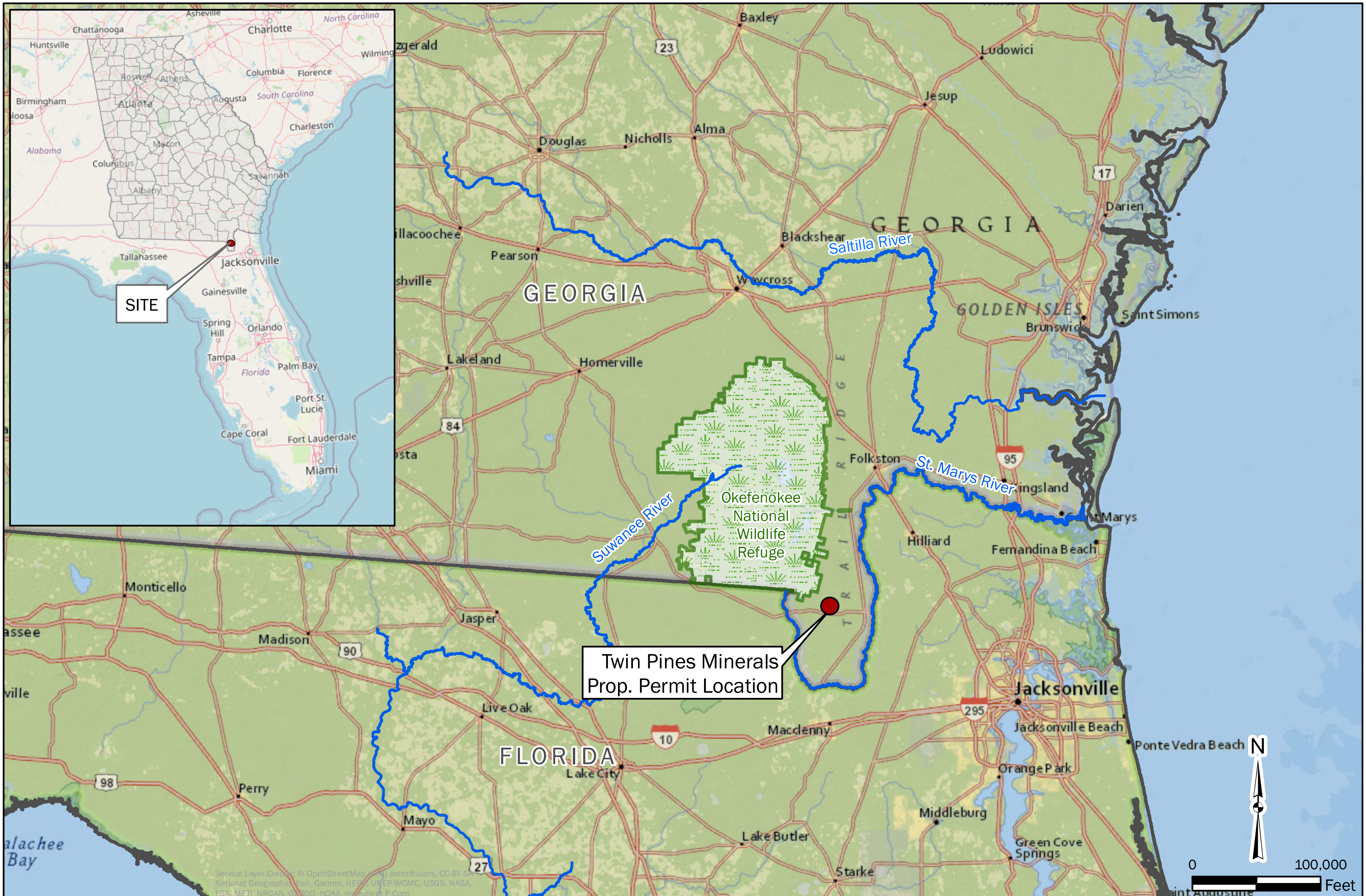

FIGURE 1: LOCATION OF THE PROPOSED SAUNDERS DEMONSTRATION MINE

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE

ST. GEORGE, CHARLTON COUNTY, GEORGIA

INSET BASEMAP: Open Street Map; BASEMAP: National Geographic World Map (See Service Layer Credits).

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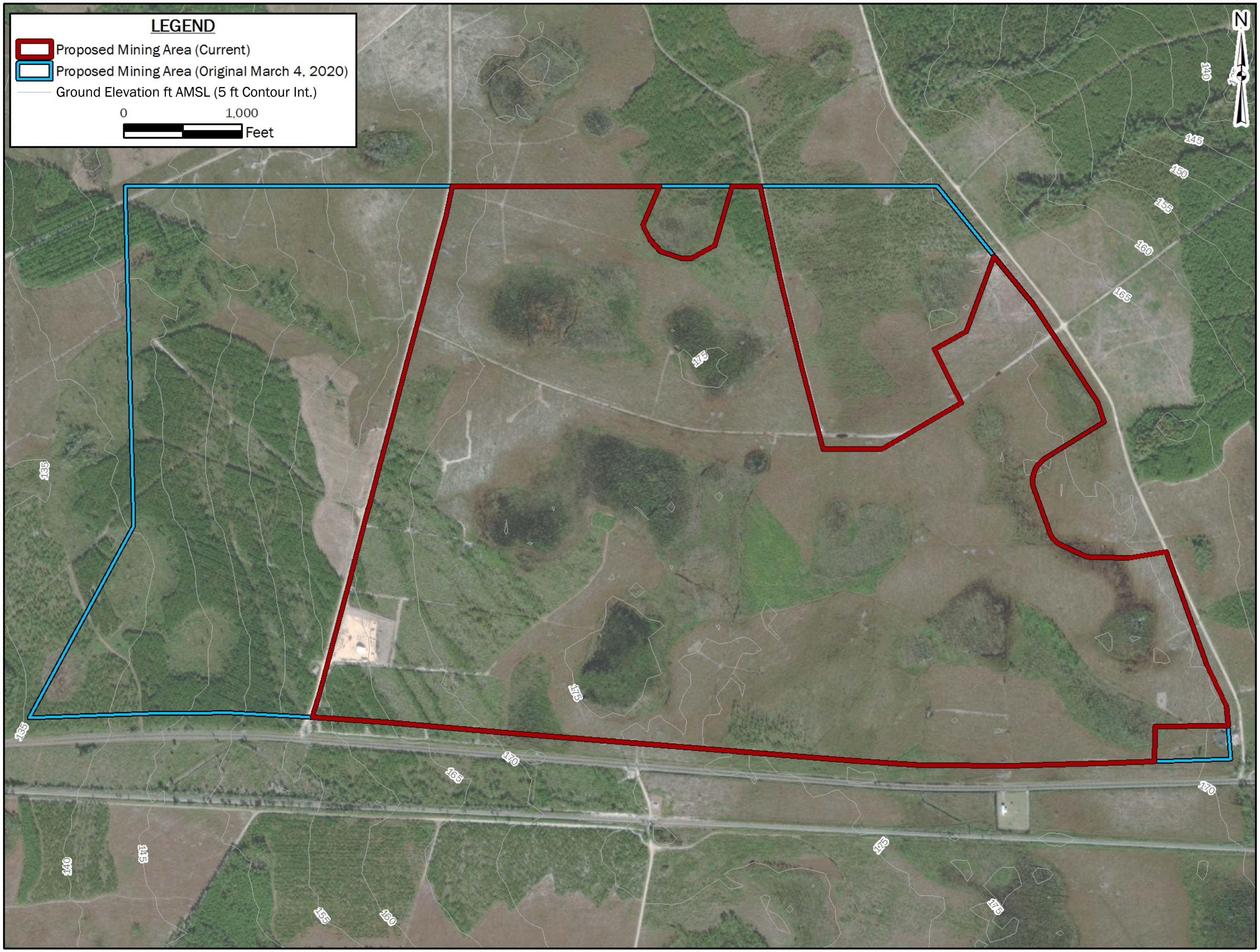

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FIGURE 2: REVISED MINE FOOTPRINT

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE

ST. GEORGE, CHARLTON COUNTY, GEORGIA

BASEMAP: Maxar, Vivid Imagery, 11/20/2019 (West, 0.5 m Resolution) & 3/24/2018 (0.46 m Resolution).

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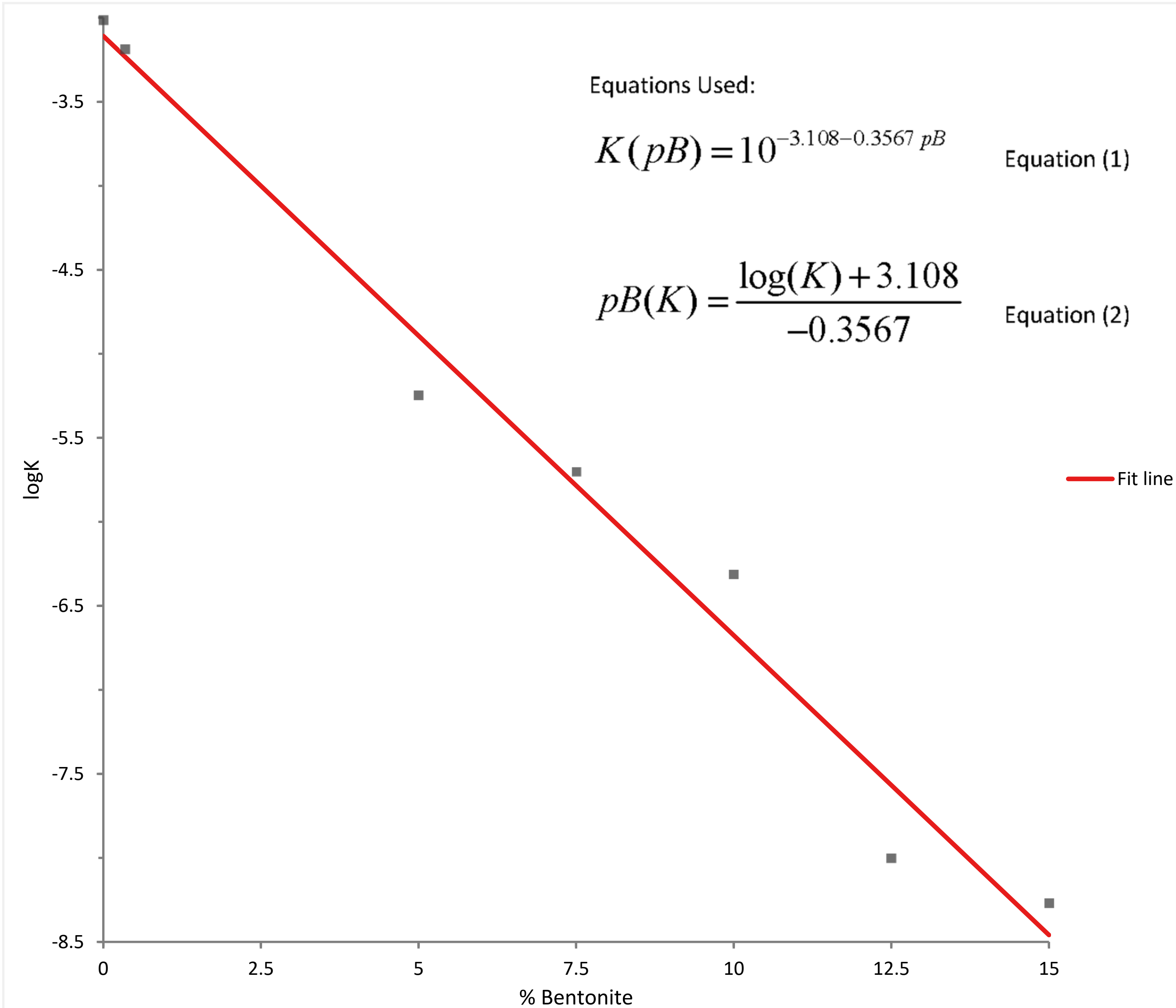

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FIGURE 3: LINEAR REGRESSION OF LOG-TRANSFORMED, AVERAGE HYDRAULIC CONDUCTIVITY VALUES FROM HOLT ET AL. (2019F)

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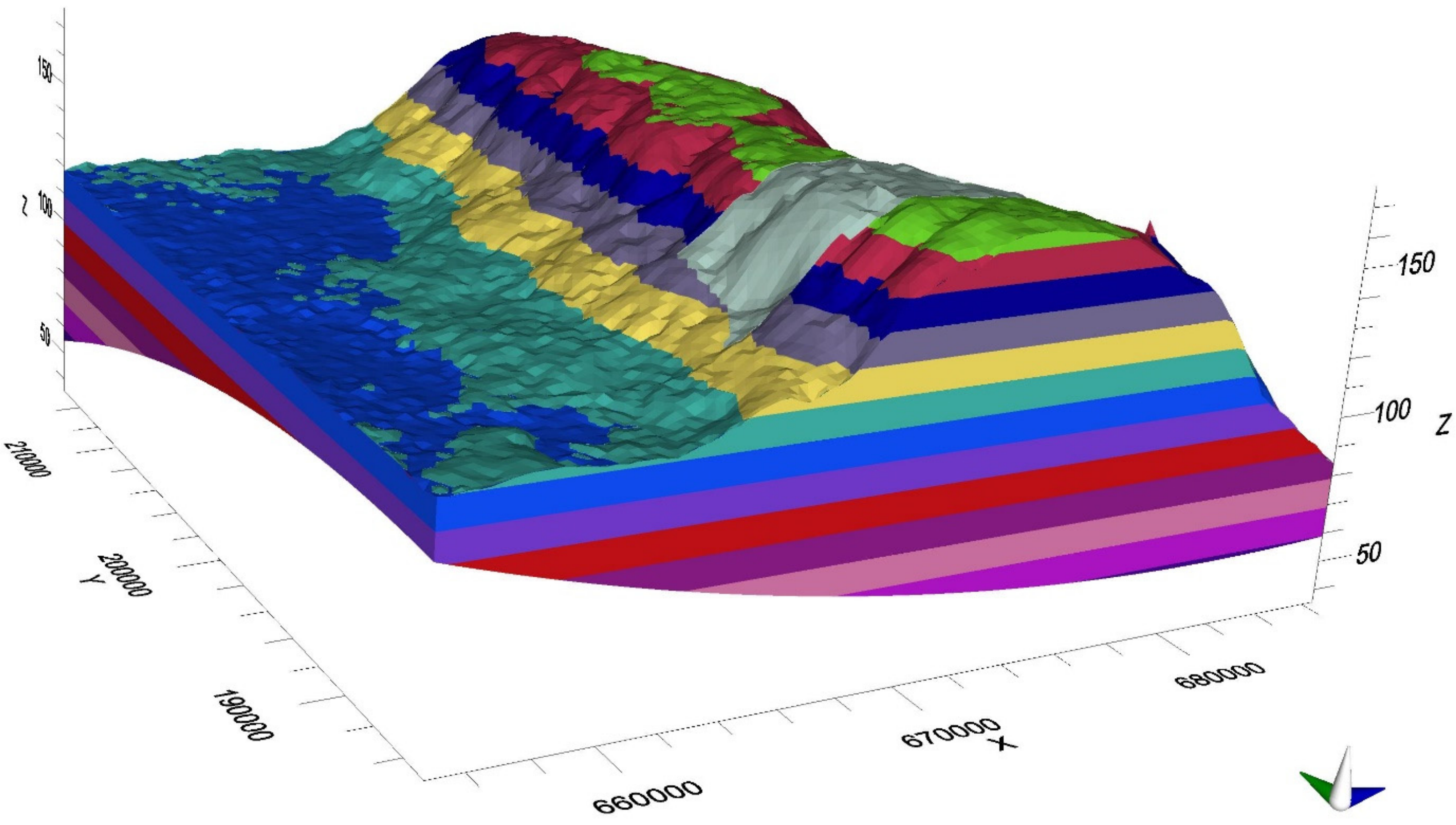

NOTE: Gray surface area represents the horizontal extent of the original mine footprint of Holt et al (2020); the current mine footprint does not extend as far west

TTL

FIGURE 4: NEW MODEL LAYER (SURFICIAL EXTENT OF THE MINING FOOTPRINT SHOWN IN GRAY) CROSS-CUTS THE UNDERLYING LAYERS OF HOLT ET AL. (2020) AND EXTENDS TO A DEPTH 10 FEET BGS
TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE
ST. GEORGE, CHARLTON COUNTY, GEORGIA

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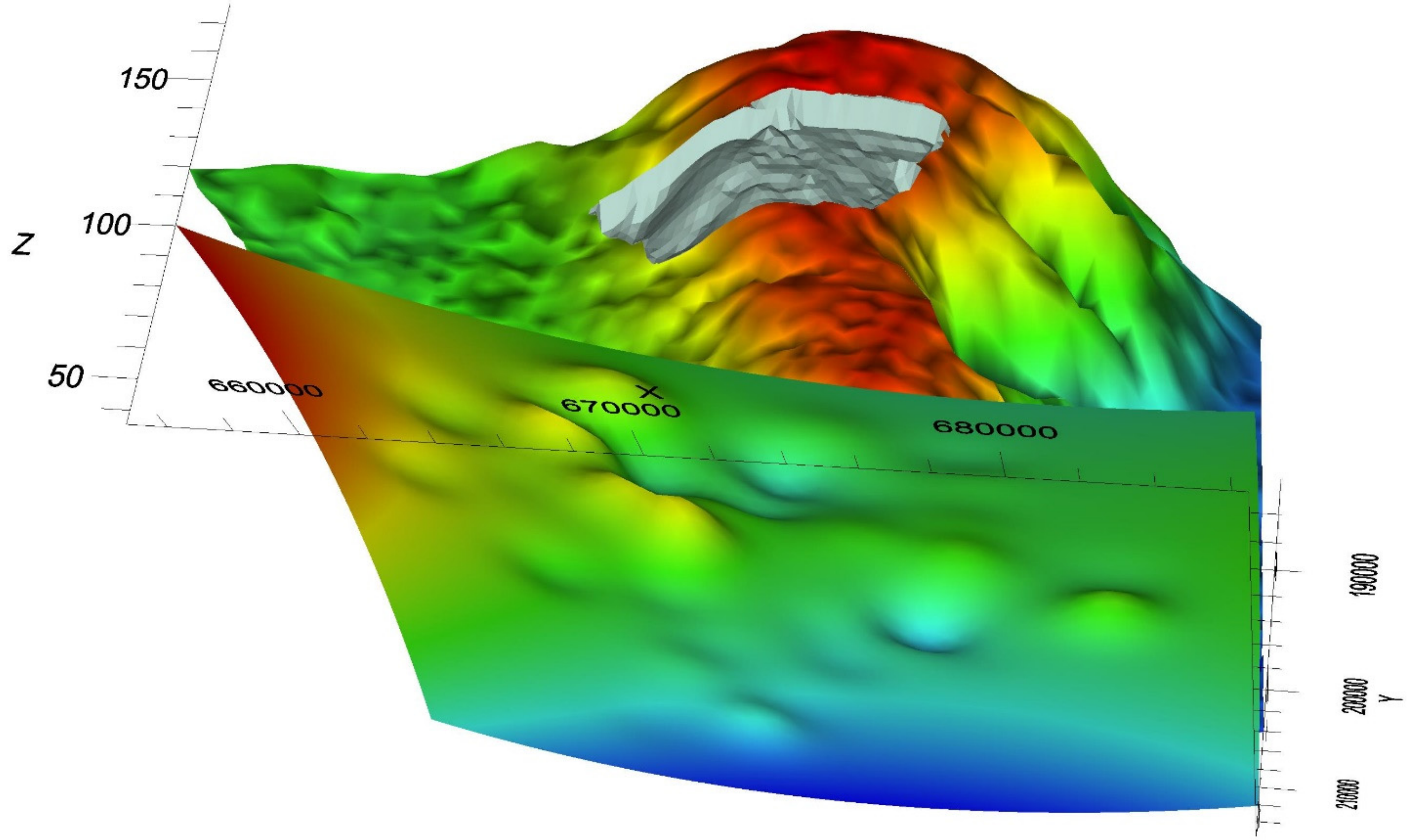

NOTE: Gray area represents the mining area at the top of the Hawthorn layer elevations.
The gray area represents the original mine footprint of Holt et al (2020); the current mine footprint does not extend as far west.

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FIGURE 5: NEW MODEL LAYER (SHOWN IN GRAY) ISOLATED BETWEEN THE LAND SURFACE AND THE TOP OF THE HAWTHORN. THE NEW LAYER IS 10 FT THICK AND MIMICKS THE LAND SURFACE
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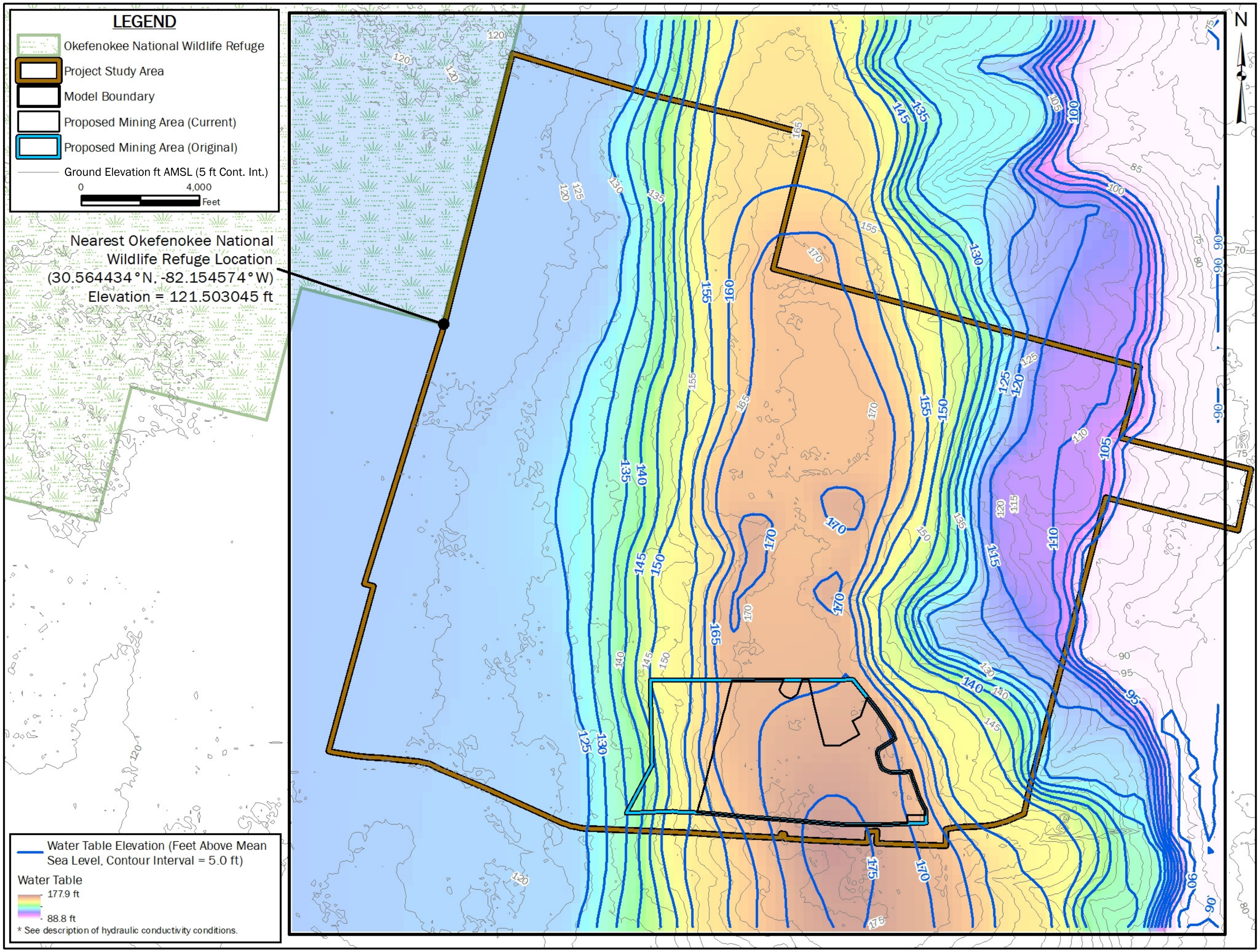

FIGURE 6: POTENTIOMETRIC SURFACE MAP OF THE HOMOGENEOUS SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-04 CM/S

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE

ST. GEORGE, CHARLTON COUNTY, GEORGIA

Note: K = Hydraulic Conductivity

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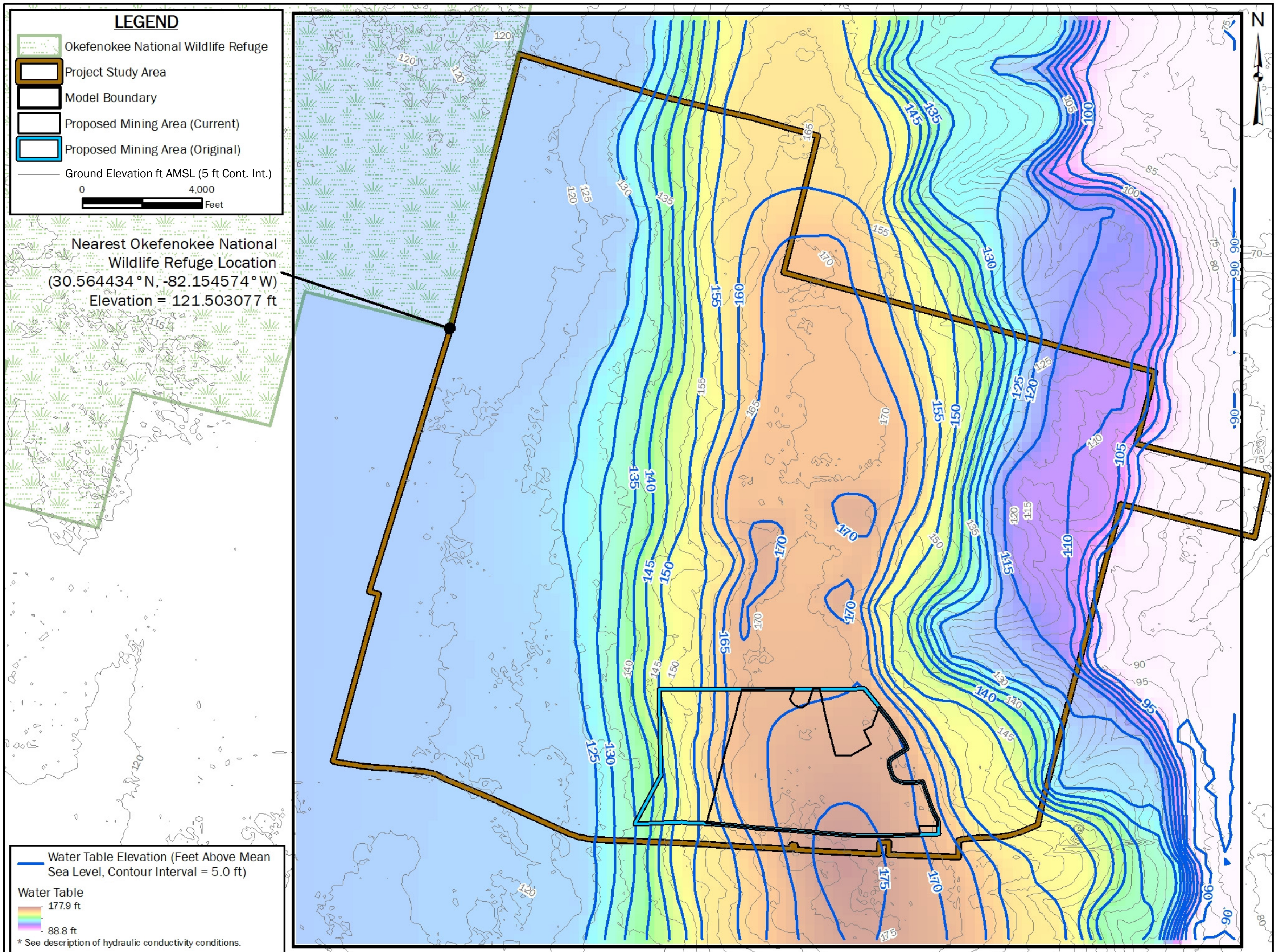

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FIGURE 7: POTENTIOMETRIC SURFACE MAP OF THE HOMOGENEOUS SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-05 CM/S

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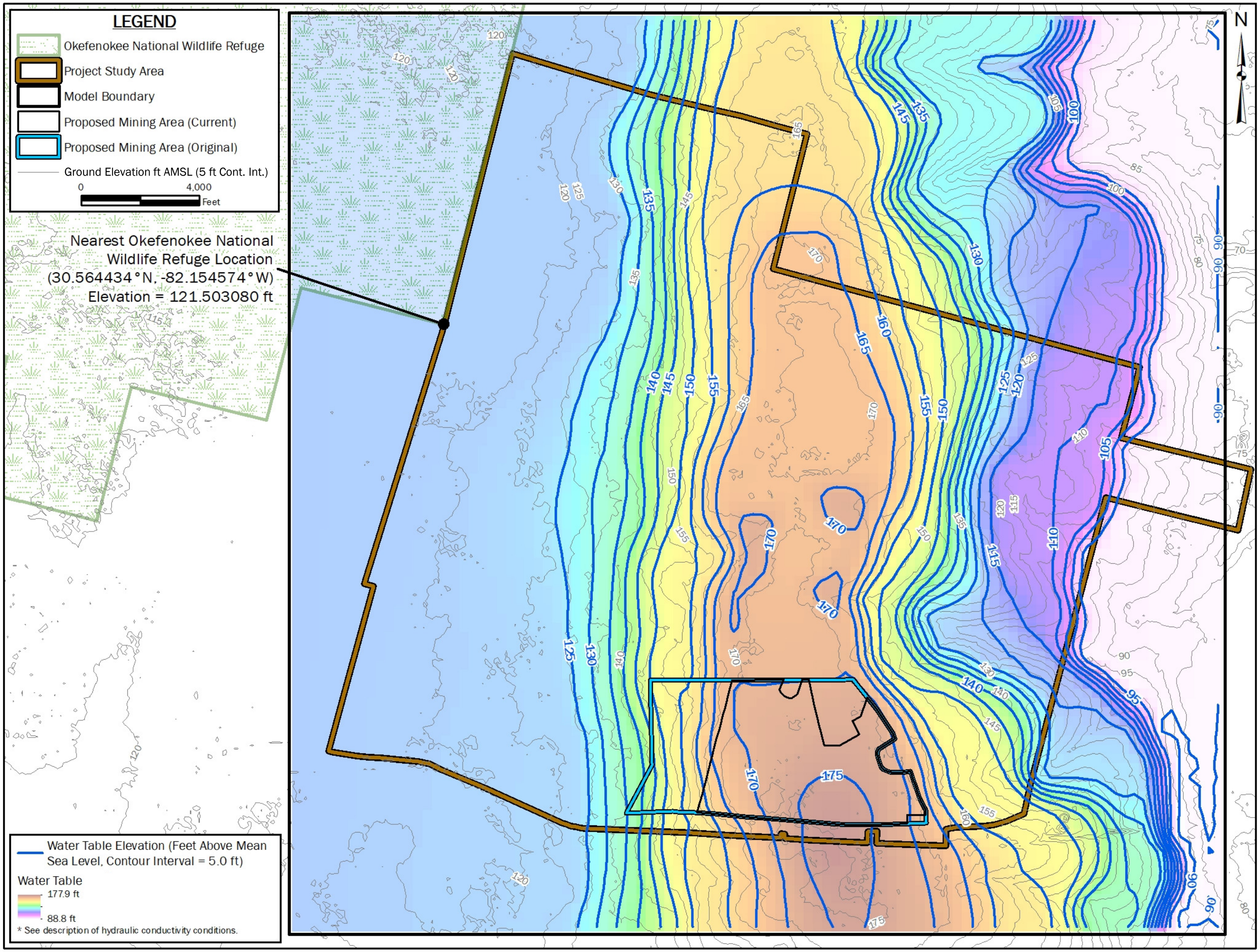

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FIGURE 8: POTENTIOMETRIC SURFACE MAP OF THE HOMOGENEOUS SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-06 CM/S
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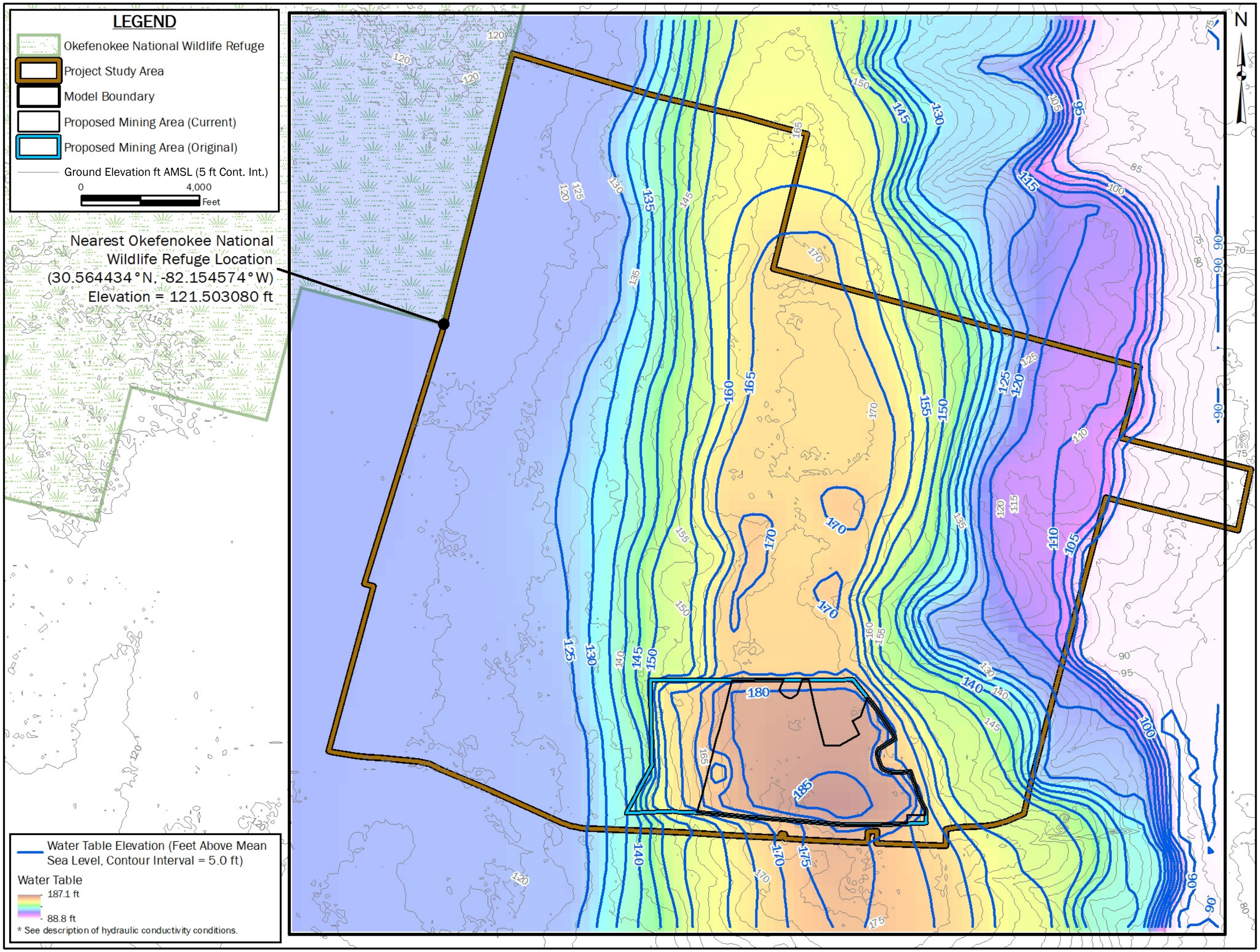

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FIGURE 9: POTENTIOMETRIC SURFACE MAP OF THE HOMOGENEOUS SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-07 CM/S

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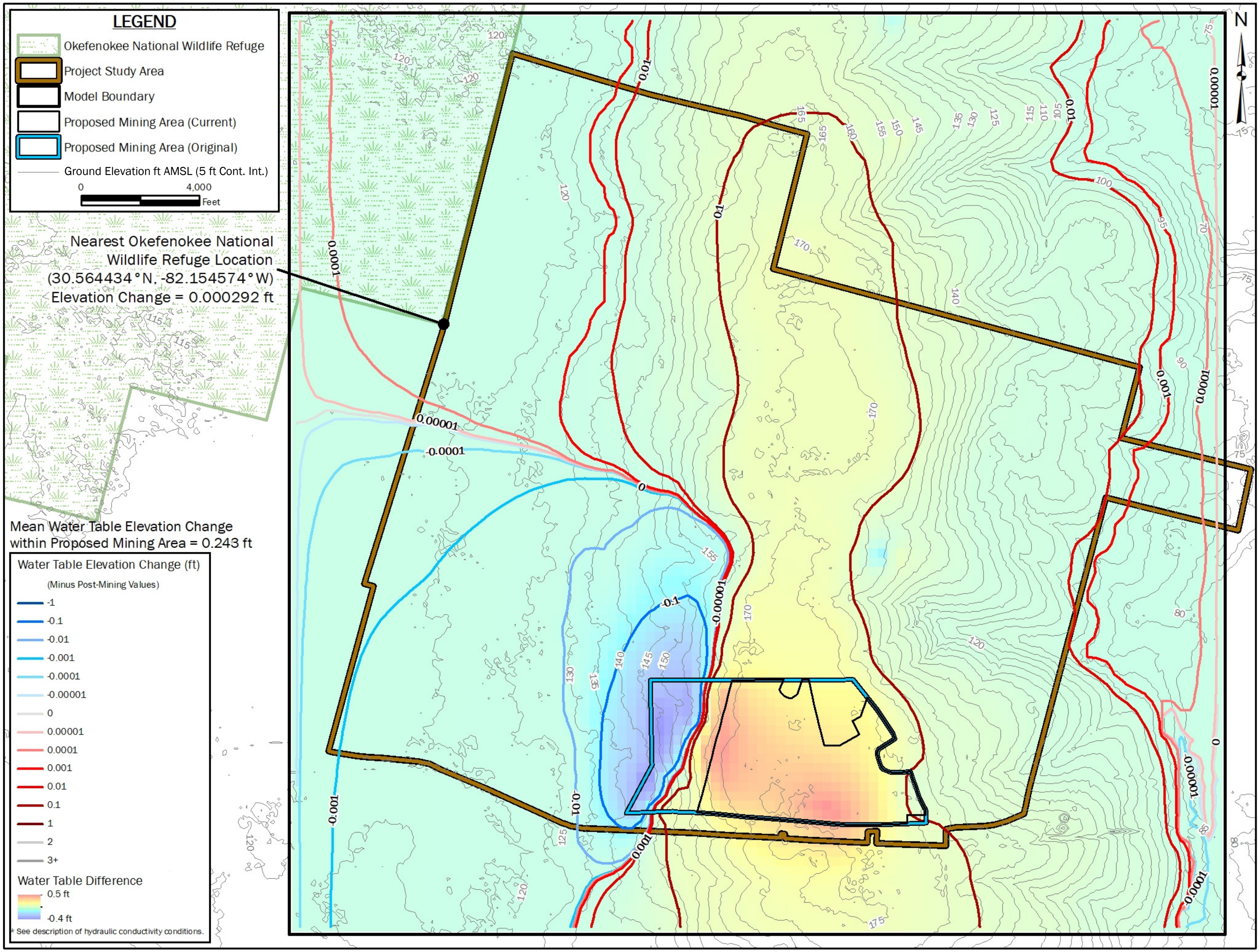

FIGURE 10: HYDRAULIC HEAD DIFFERENCE BETWEEN HOMOGENEOUS SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-04 CM/S

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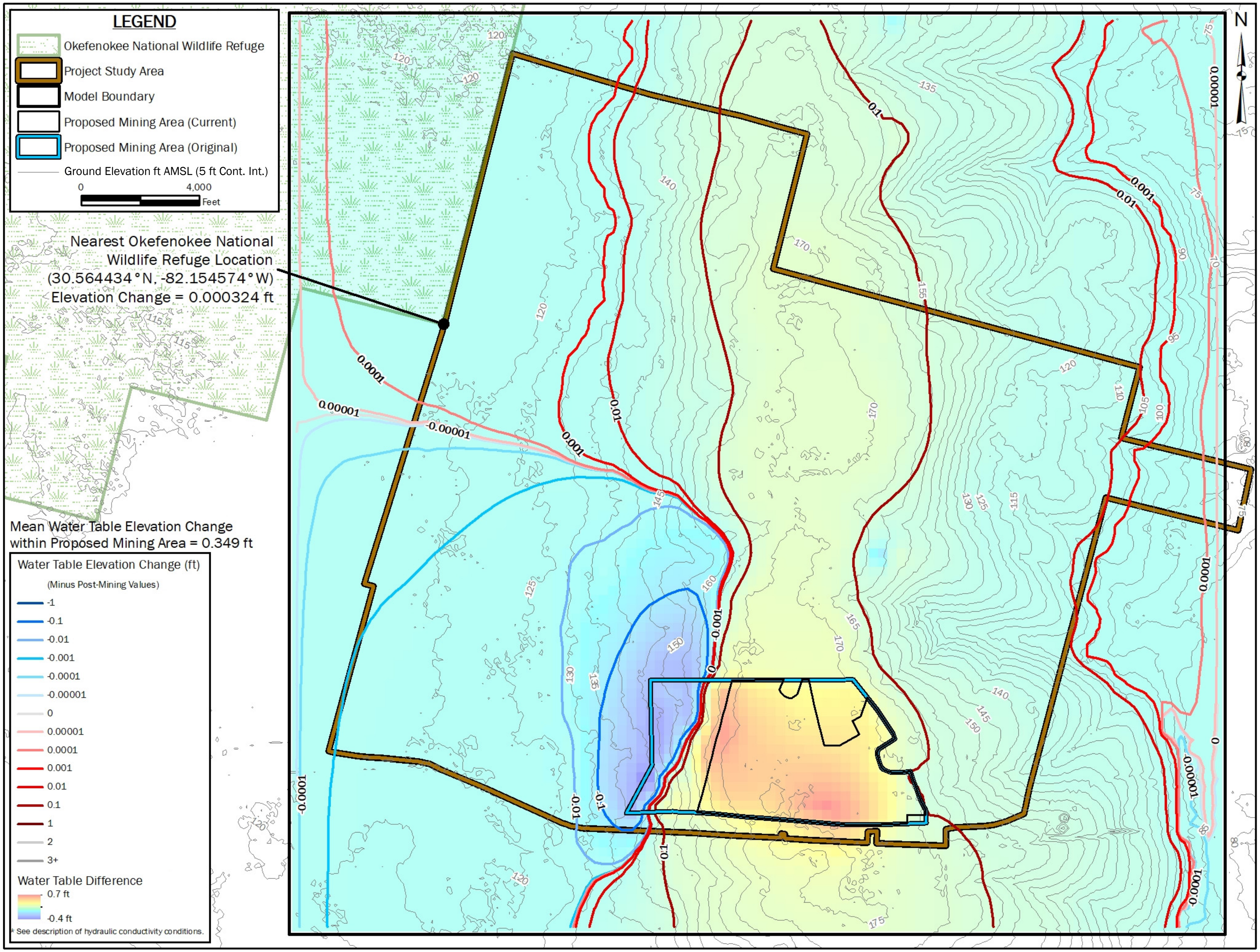

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FIGURE 11: HYDRAULIC HEAD DIFFERENCE BETWEEN HOMOGENEOUS SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-05 CM/S
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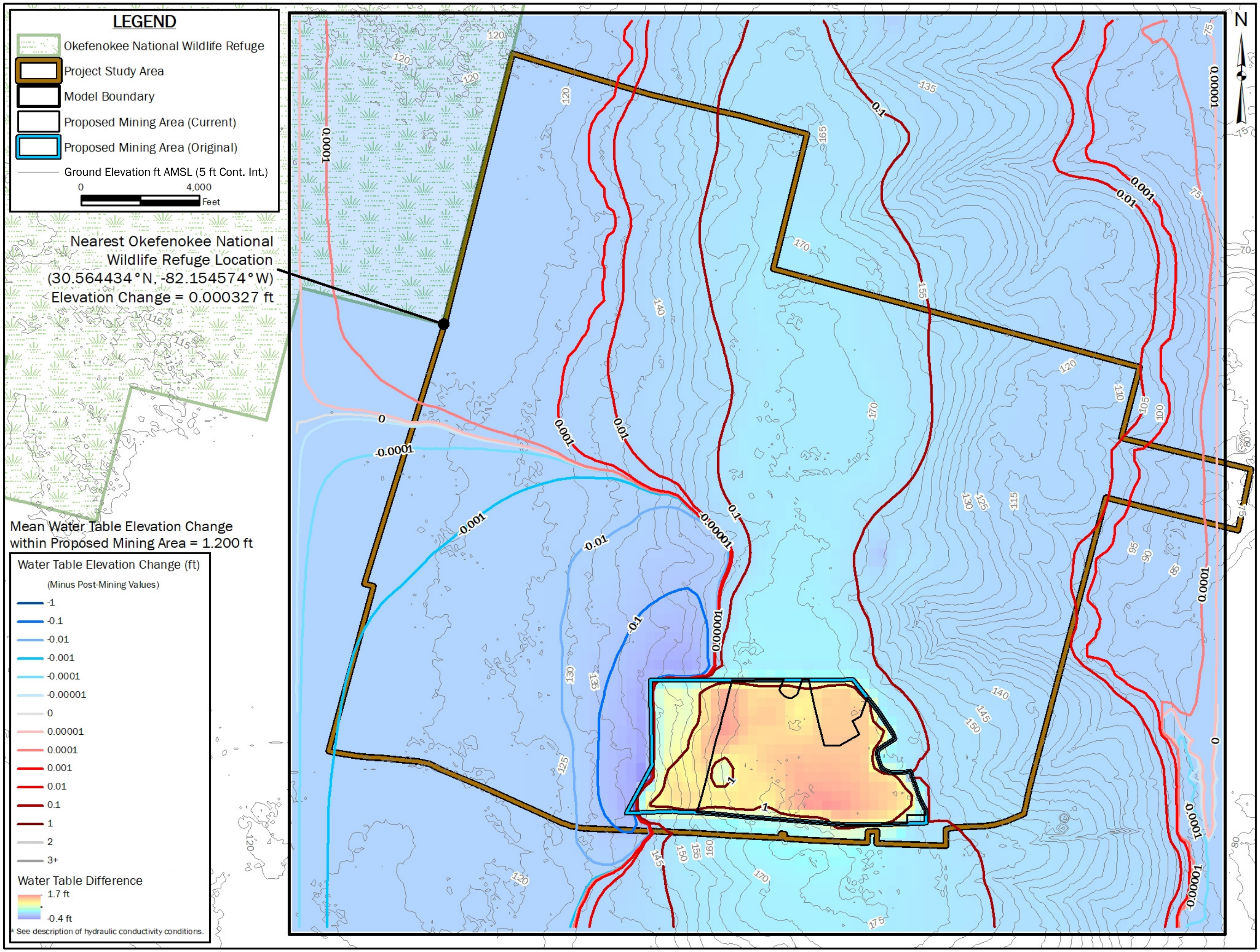

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FIGURE 12: HYDRAULIC HEAD DIFFERENCE BETWEEN HOMOGENEOUS SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-06 CM/S
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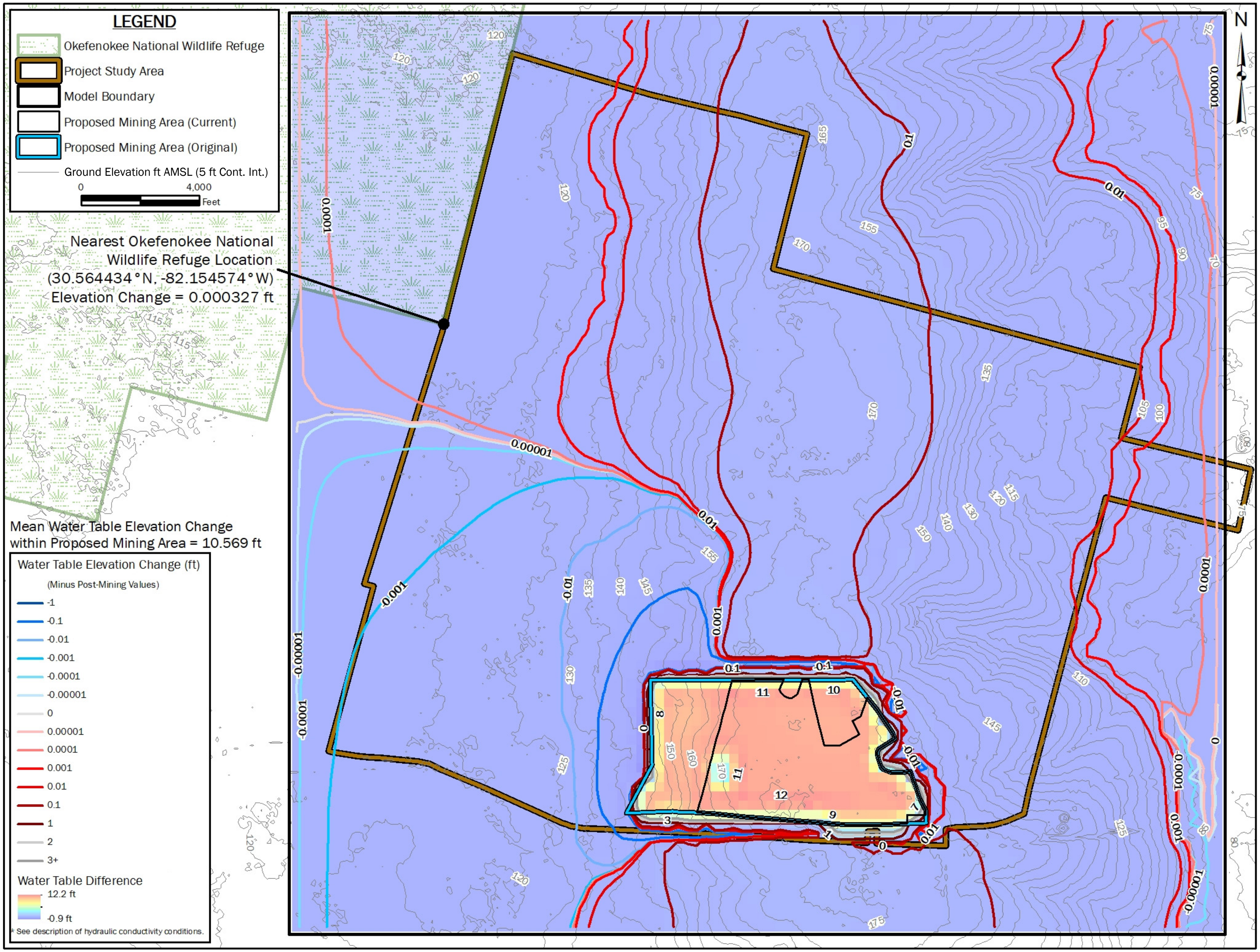

TTL	FIGURE 13: HYDRAULIC HEAD DIFFERENCE BETWEEN HOMOGENEOUS SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-07 CM/S TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE ST. GEORGE, CHARLTON COUNTY, GEORGIA Note: K = Hydraulic Conductivity	DRAWN BY: DEK CHECKED BY: JRS DRAWING DATE: 11/8/2020 REVISION DATE: N/A TTL JOB NO.: 000180200804.00 APPROX. SCALE: 1" = 4,000 ft

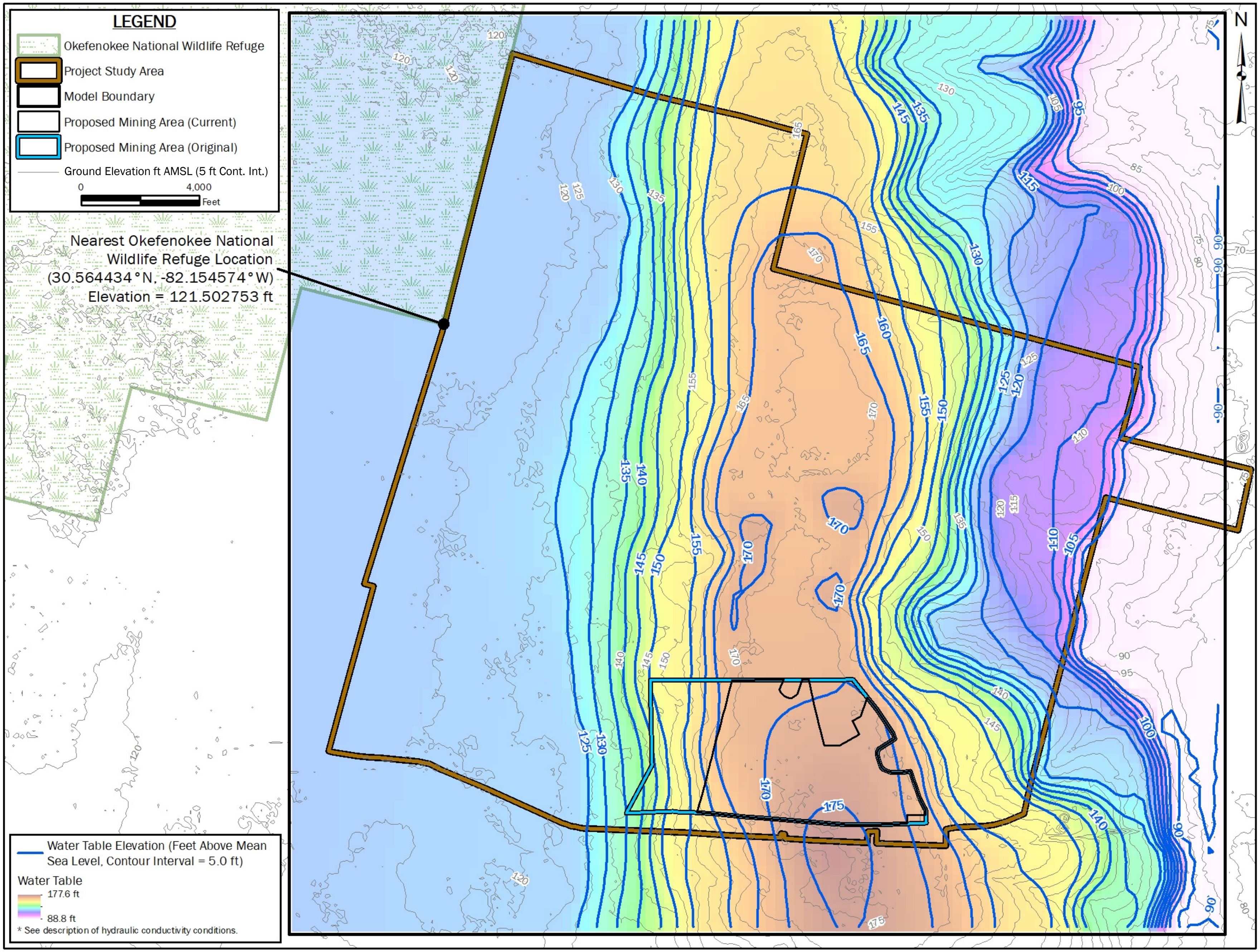

FIGURE 14: POTENTIOMETRIC SURFACE MAP OF THE LAYERED SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-04 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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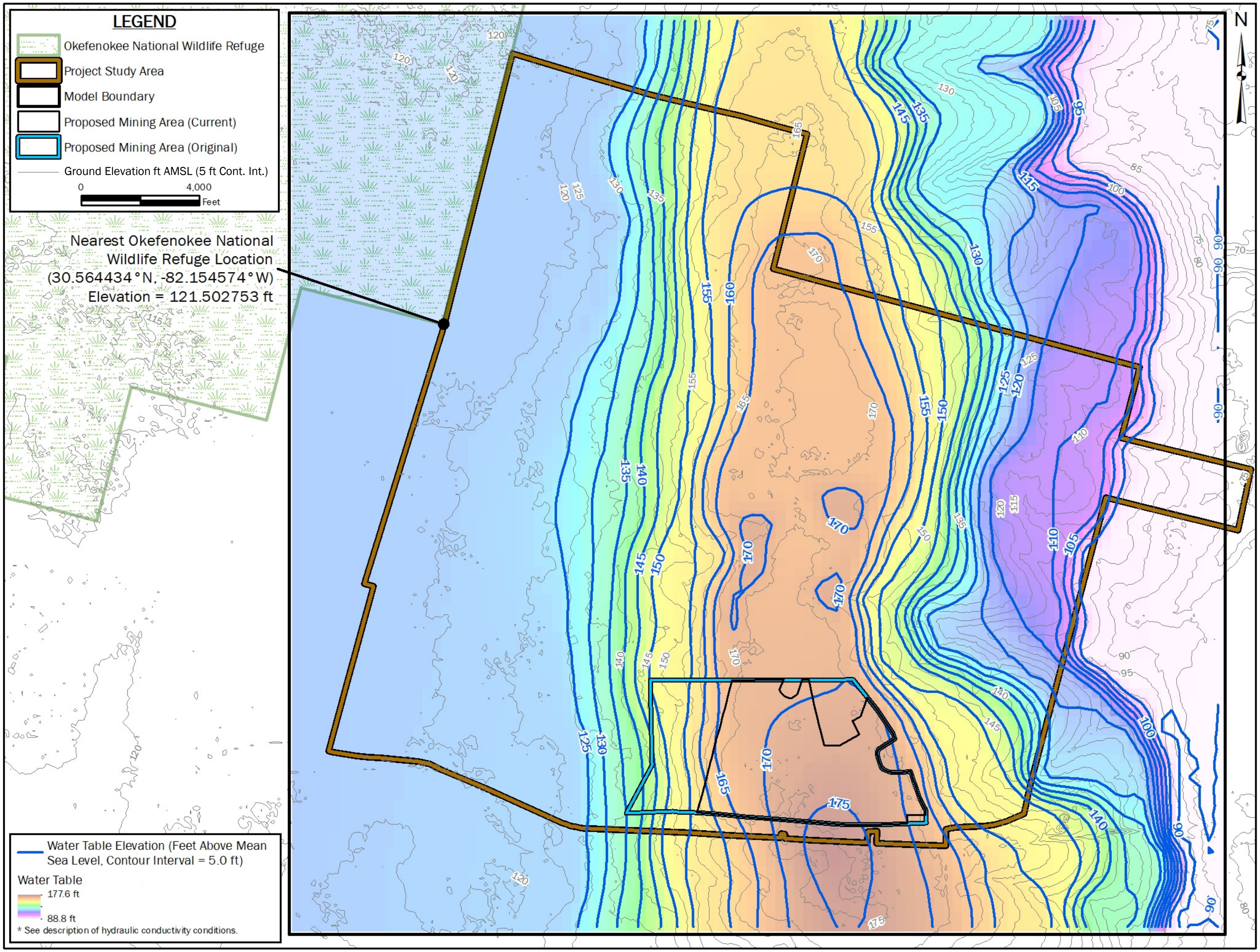

FIGURE 15: POTENTIOMETRIC SURFACE MAP OF THE LAYERED SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-05 CM/S & THE HORIZONTAL K IS 1E-03 CM/S
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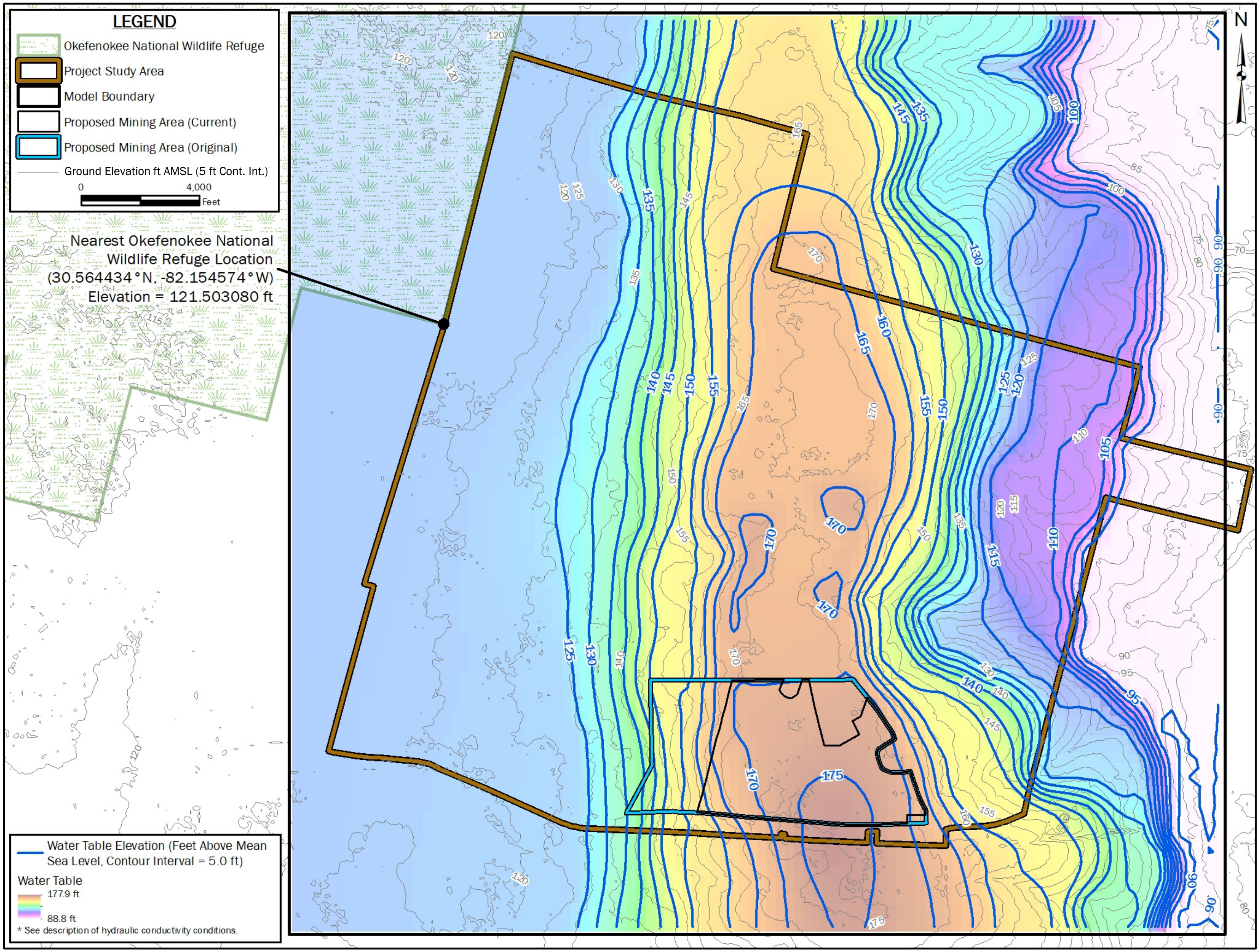

FIGURE 16: POTENTIOMETRIC SURFACE MAP OF THE LAYERED SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-06 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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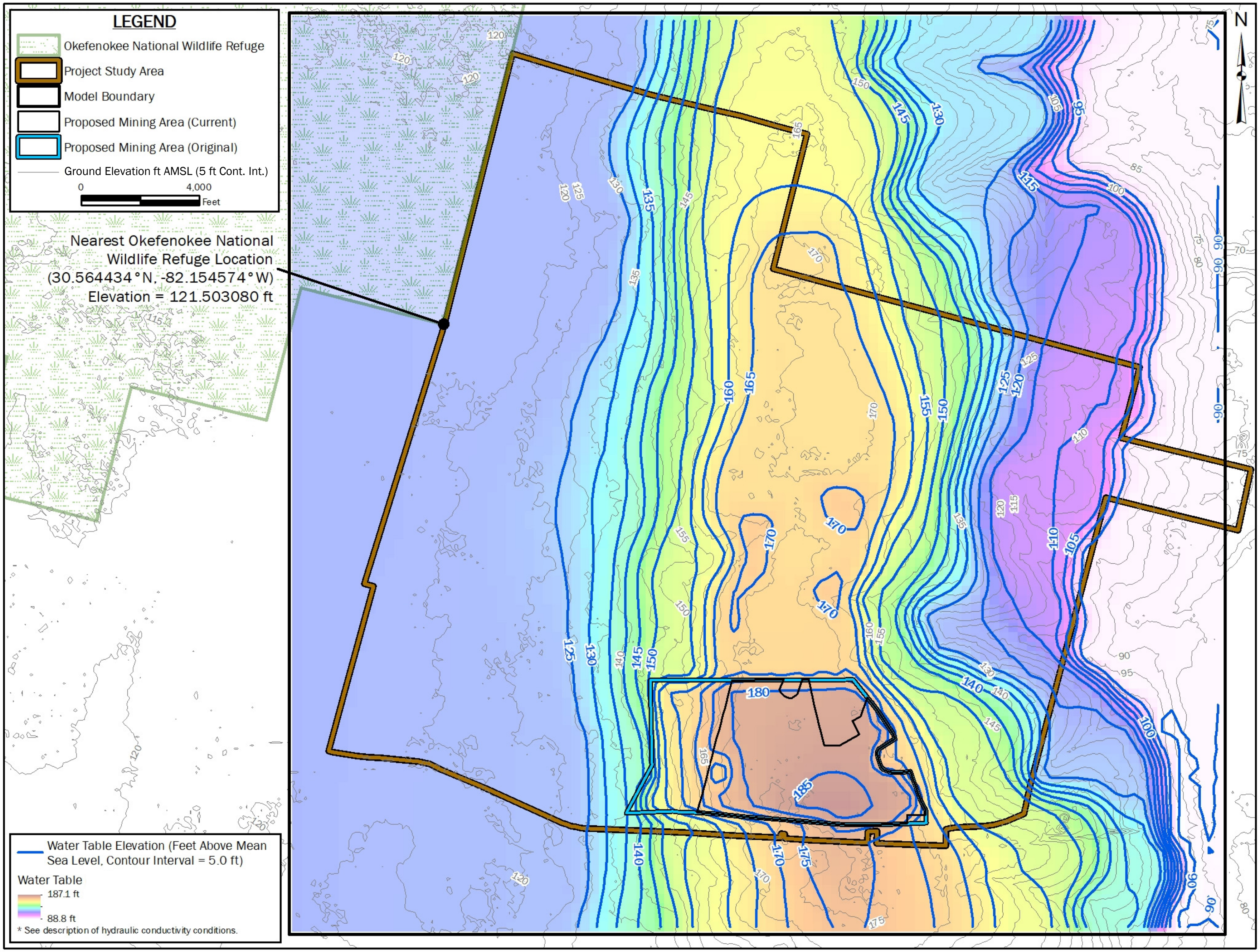

FIGURE 17: POTENTIOMETRIC SURFACE MAP OF THE LAYERED SCENARIO MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-07 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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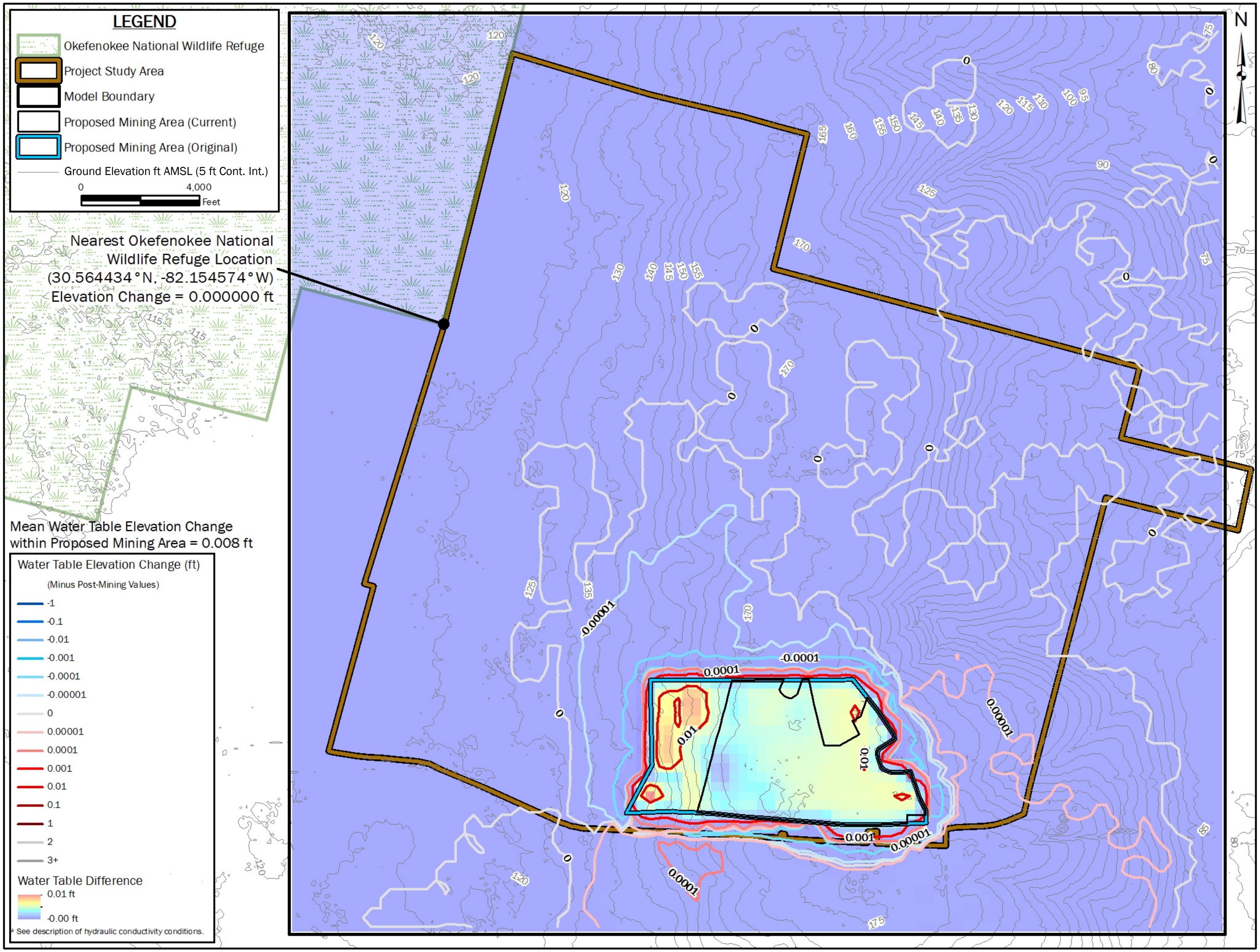

FIGURE 18: HYDRAULIC HEAD DIFFERENCE BETWEEN LAYERED SCENARIO HERE MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-04 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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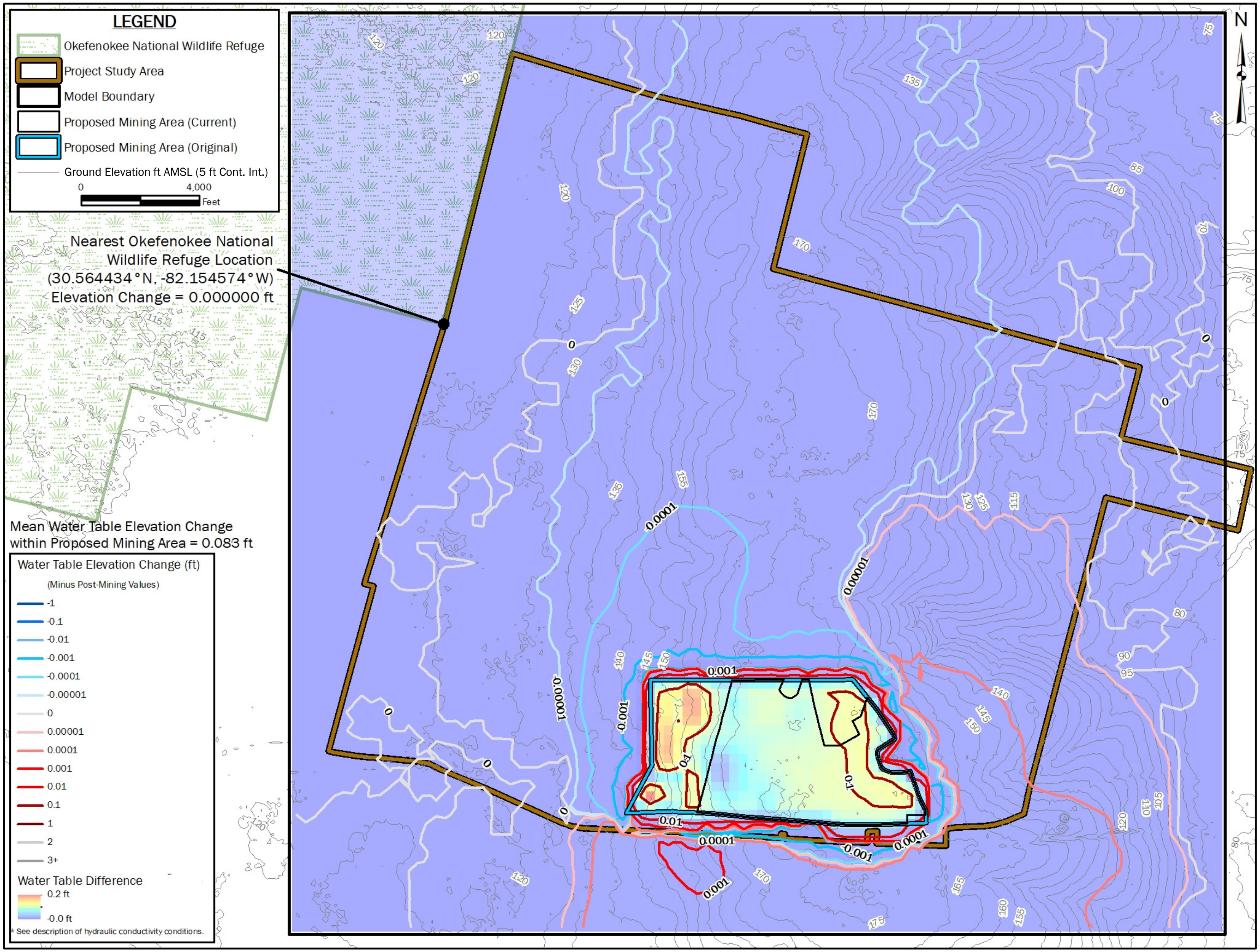

FIGURE 19: HYDRAULIC HEAD DIFFERENCE BETWEEN LAYERED SCENARIO HERE MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-05 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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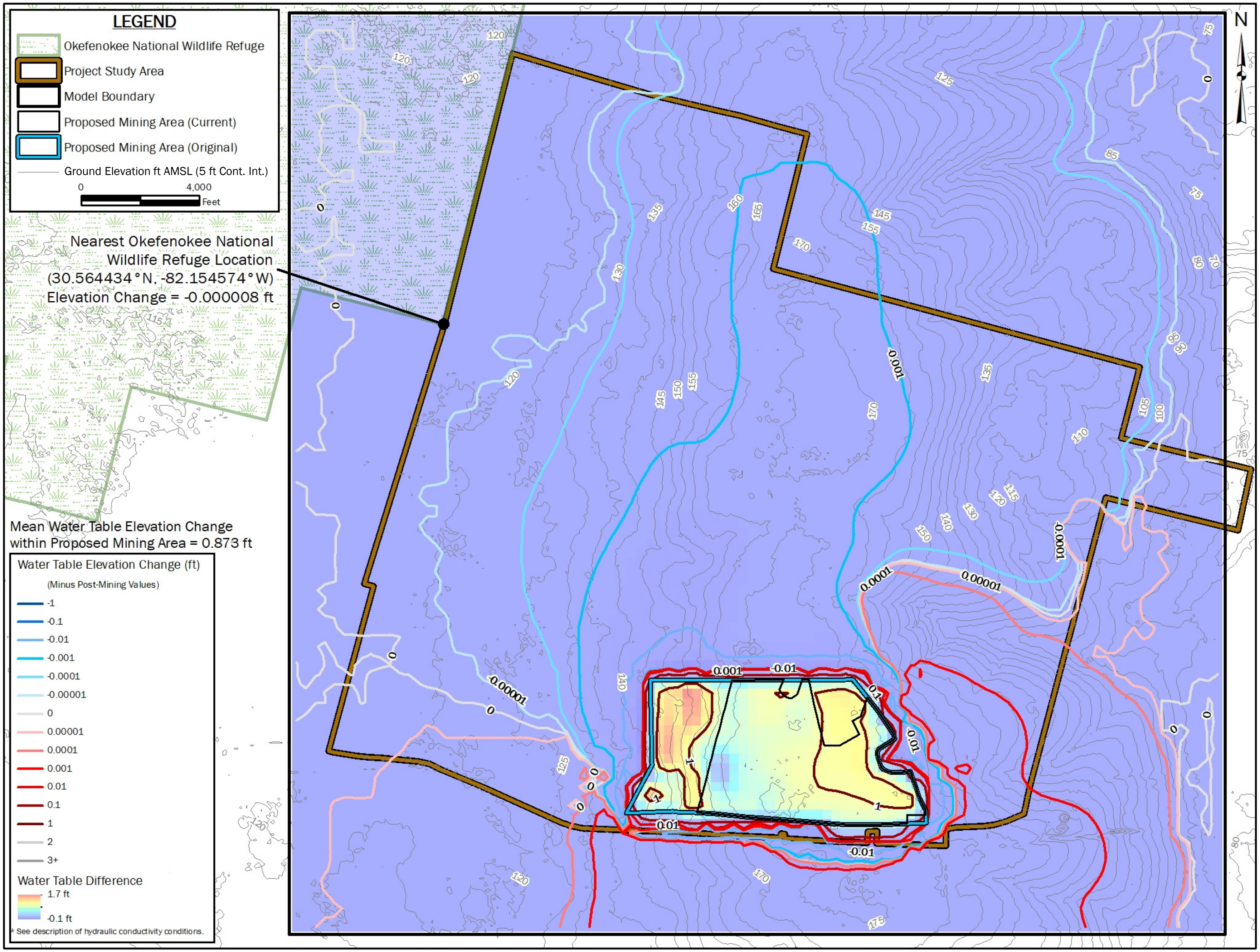

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FIGURE 20: HYDRAULIC HEAD DIFFERENCE BETWEEN LAYERED SCENARIO HERE MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-06 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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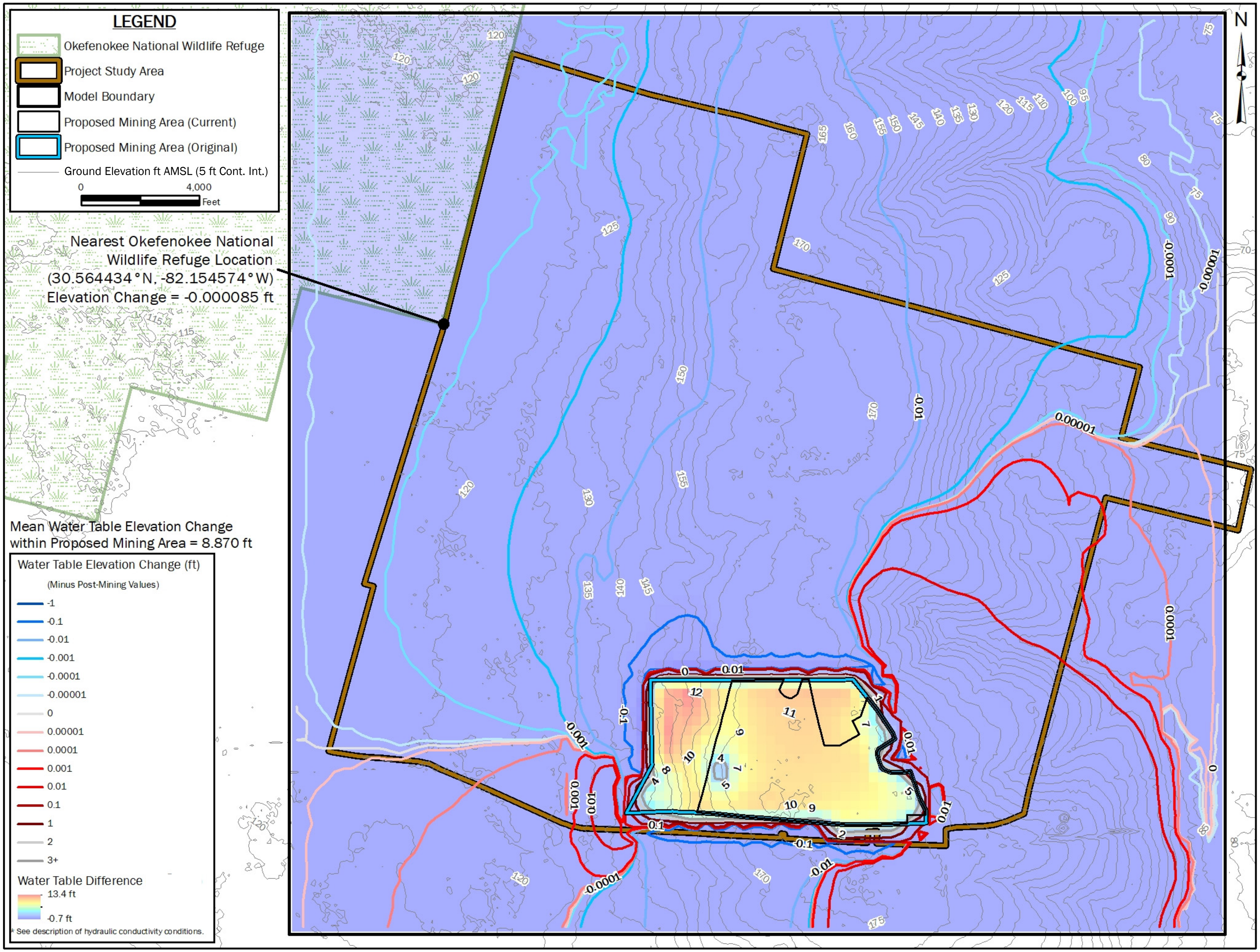

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FIGURE 21: HYDRAULIC HEAD DIFFERENCE BETWEEN LAYERED SCENARIO HERE MODELED HERE & POST-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-07 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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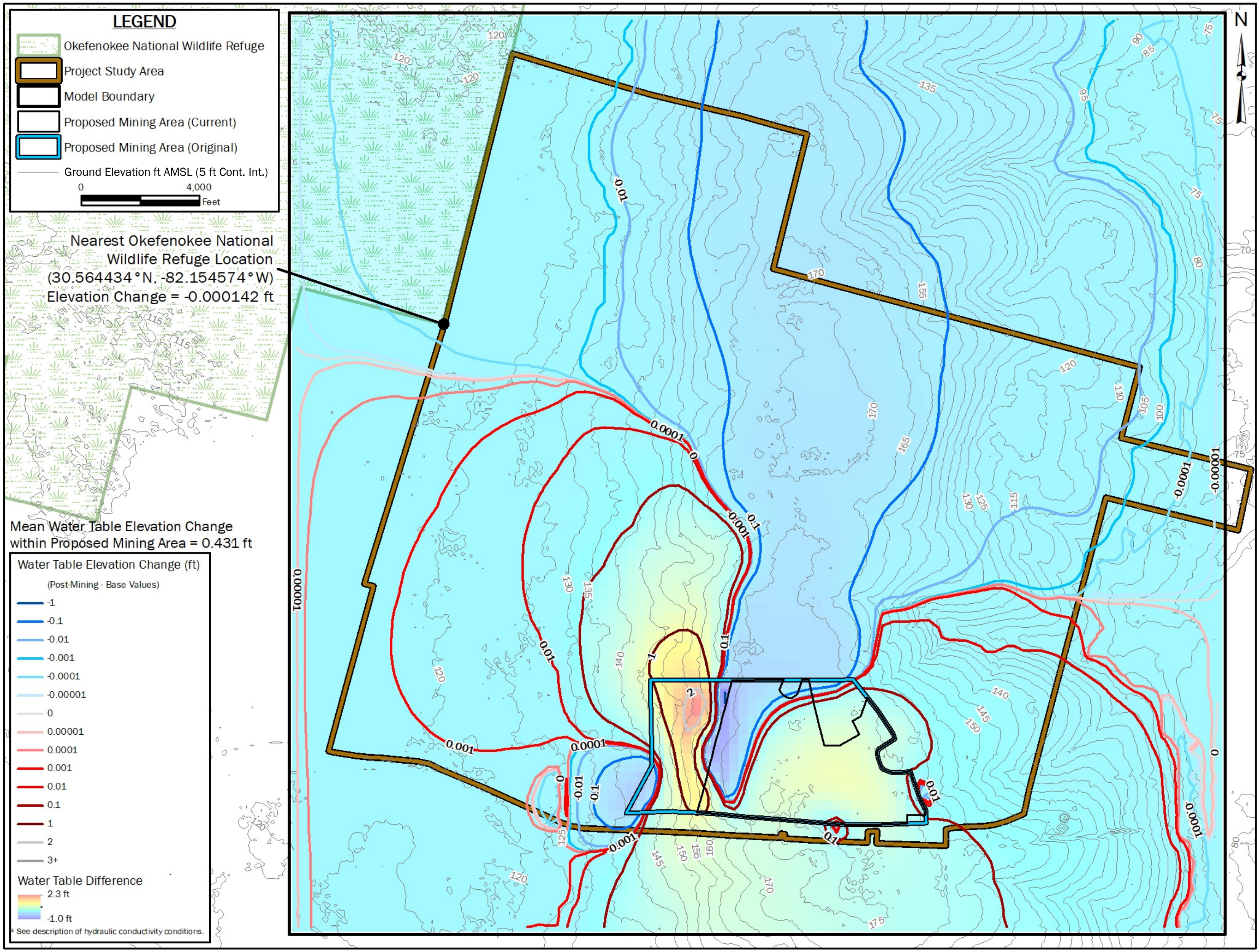

FIGURE 22: HYDRAULIC HEAD DIFFERENCE BETWEEN HOMOGENEOUS SCENARIO MODELED HERE & PRE-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-04 CM/S

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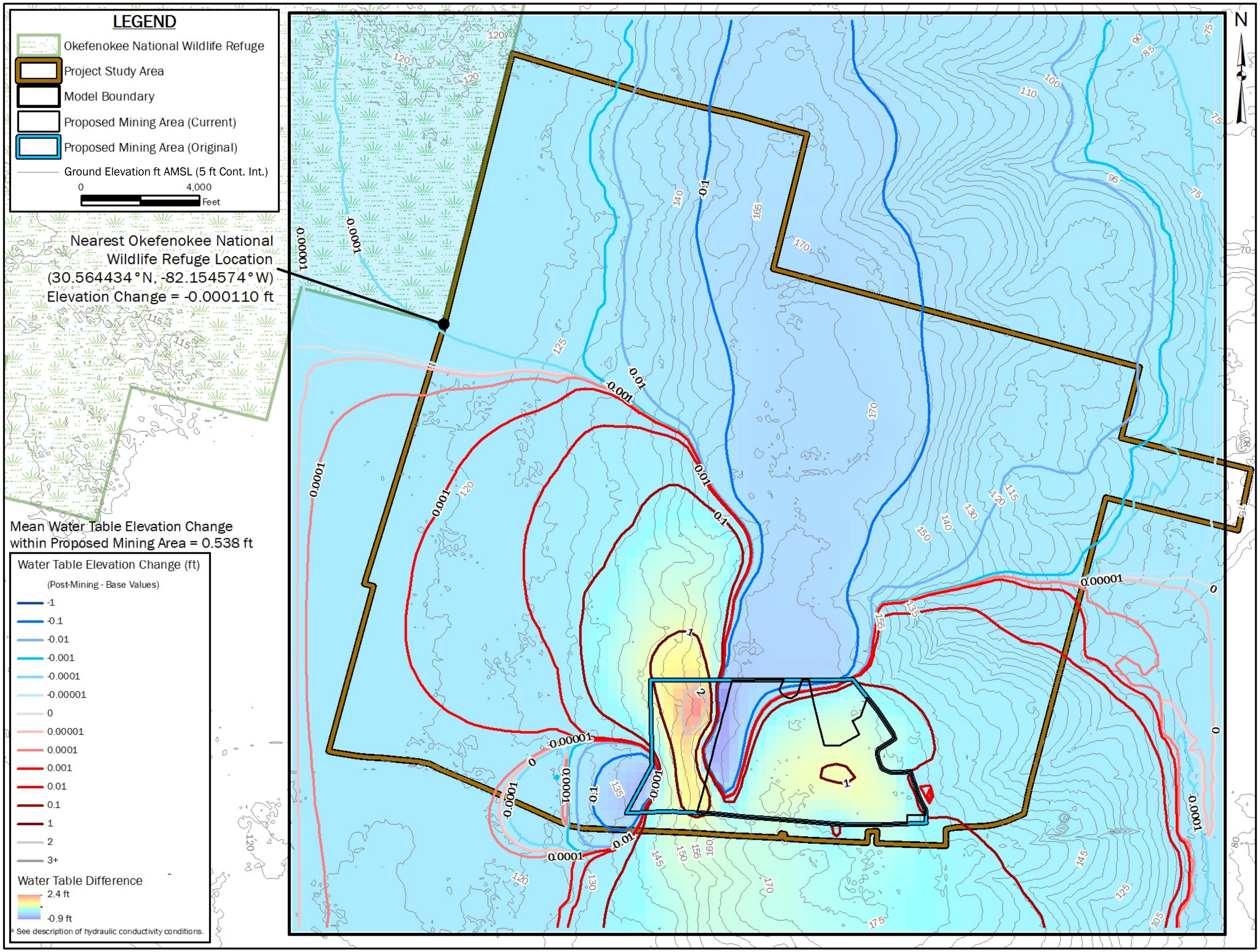

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FIGURE 23: HYDRAULIC HEAD DIFFERENCE BETWEEN HOMOGENEOUS SCENARIO MODELED HERE & PRE-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-05 CM/S
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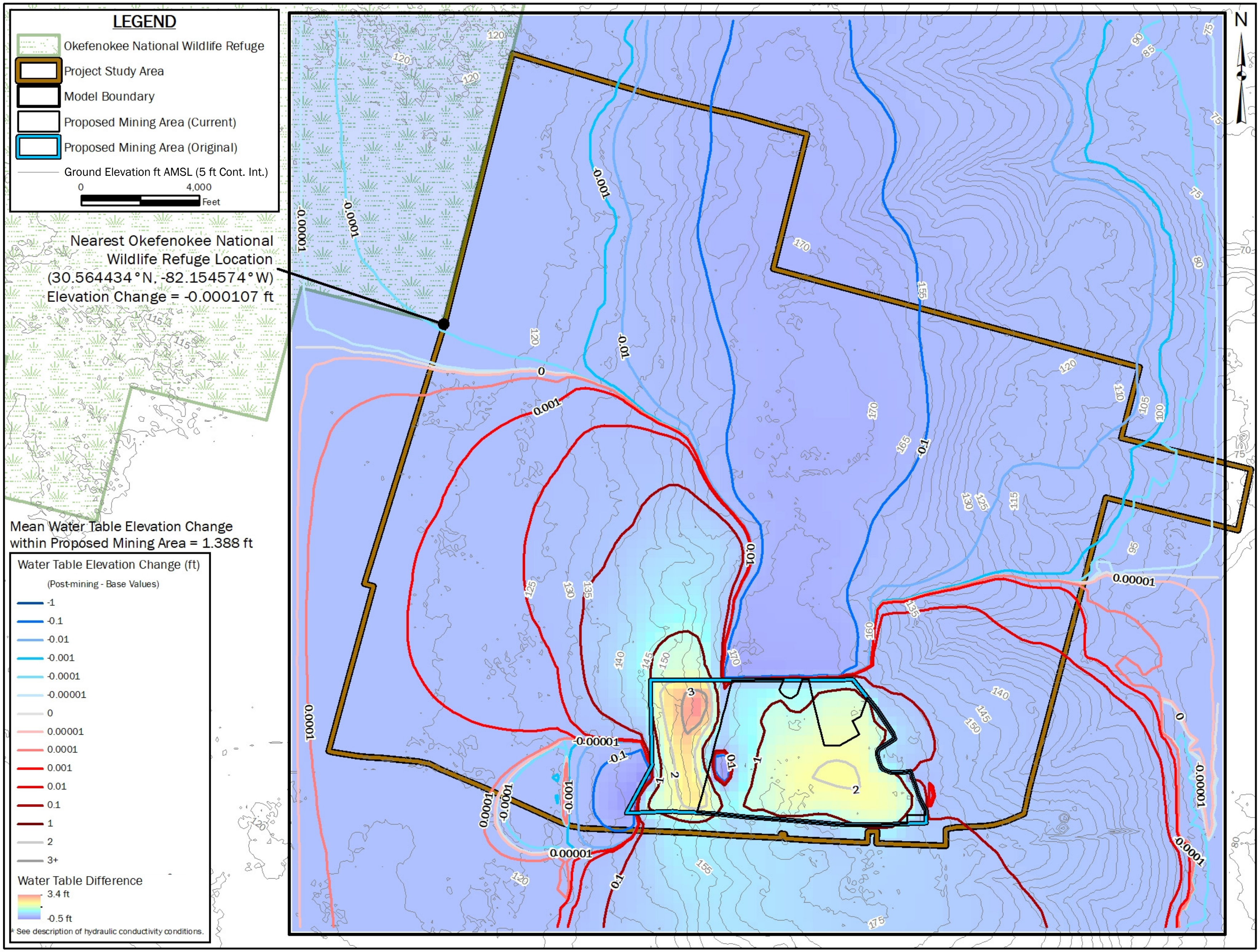

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FIGURE 24: HYDRAULIC HEAD DIFFERENCE BETWEEN HOMOGENEOUS SCENARIO MODELED HERE & PRE-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-06 CM/S
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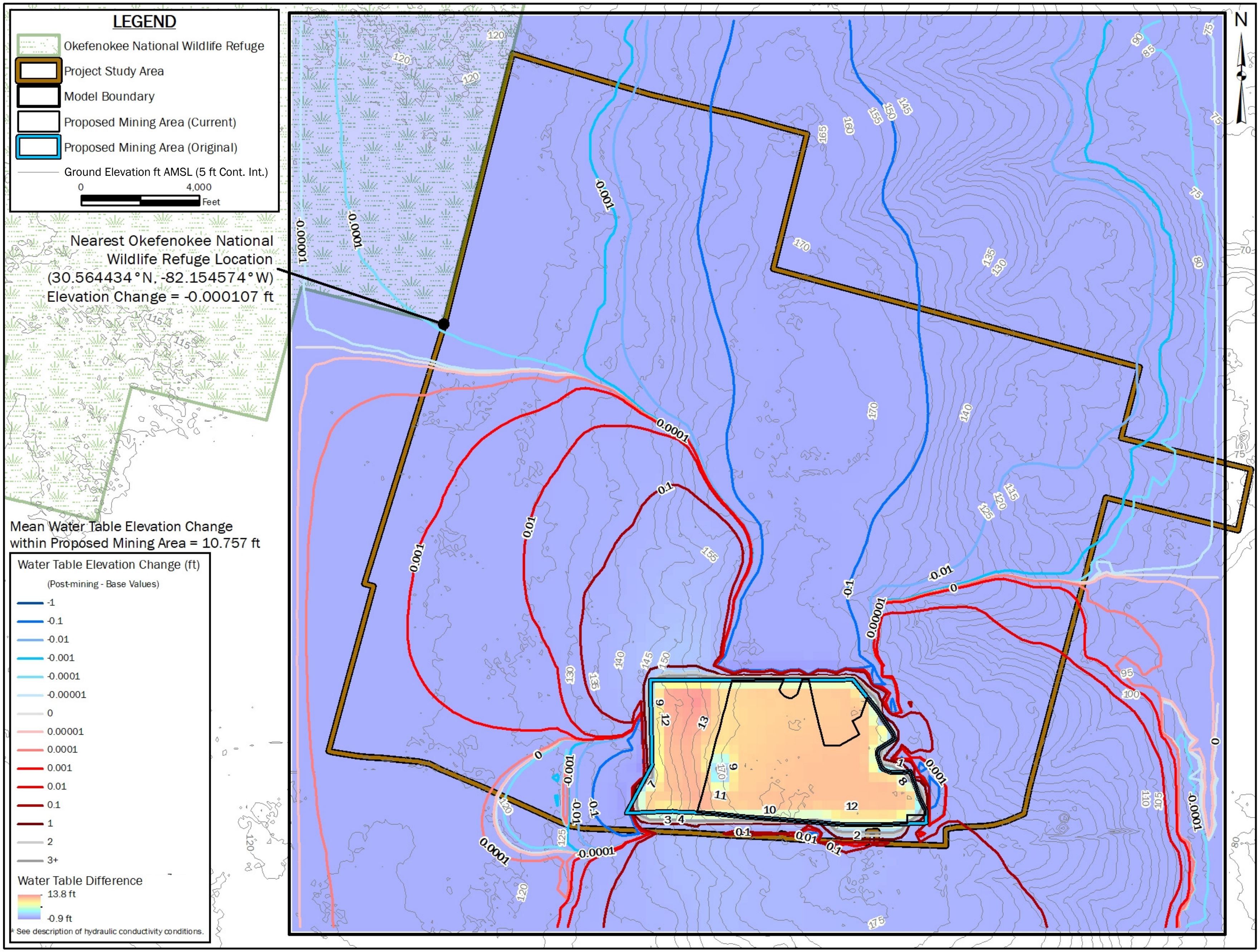

FIGURE 25: HYDRAULIC HEAD DIFFERENCE BETWEEN HOMOGENEOUS SCENARIO MODELED HERE & PRE-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL & HORIZONTAL K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-07 CM/S

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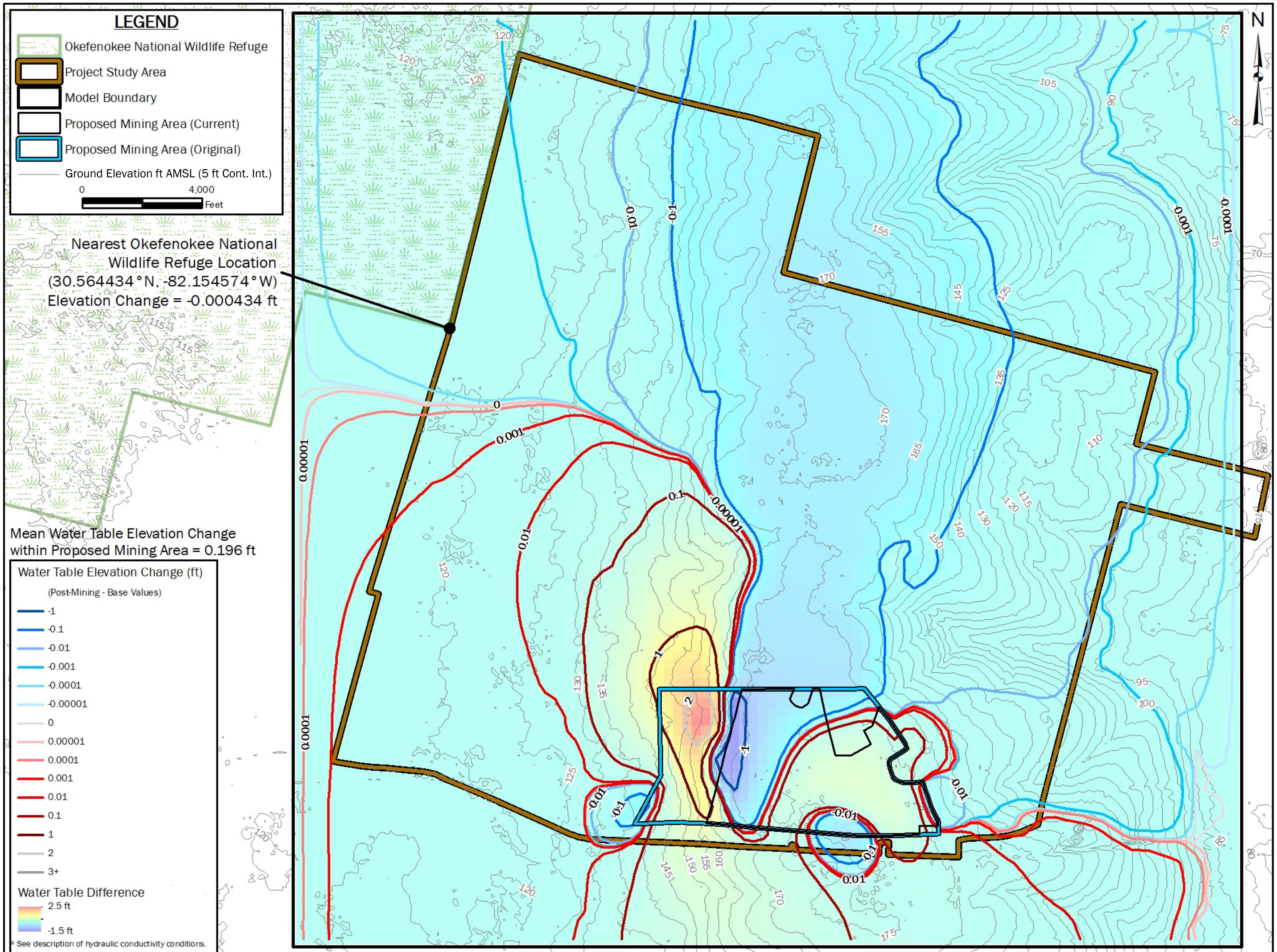

FIGURE 26: HYDRAULIC HEAD DIFFERENCE BETWEEN LAYERED SCENARIO HERE MODELED HERE & PRE-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-04 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

TWIN PINES MINERALS, LLC SAUNDERS DEMONSTRATION MINE

ST. GEORGE, CHARLTON COUNTY, GEORGIA

Note: K = Hydraulic Conductivity

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DRAWING DATE:	11/8/2020
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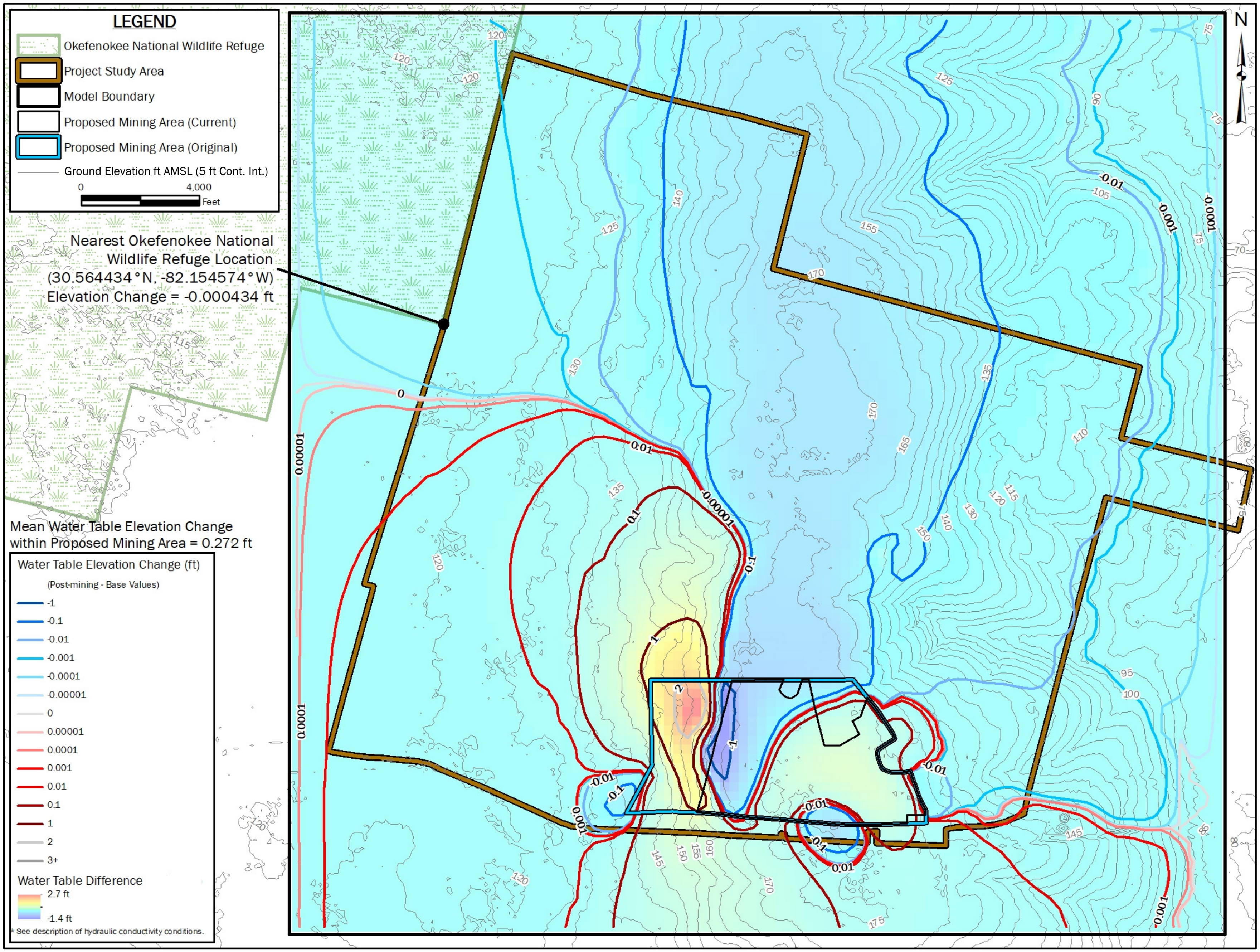

FIGURE 27: HYDRAULIC HEAD DIFFERENCE BETWEEN LAYERED SCENARIO HERE MODELED HERE & PRE-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-05 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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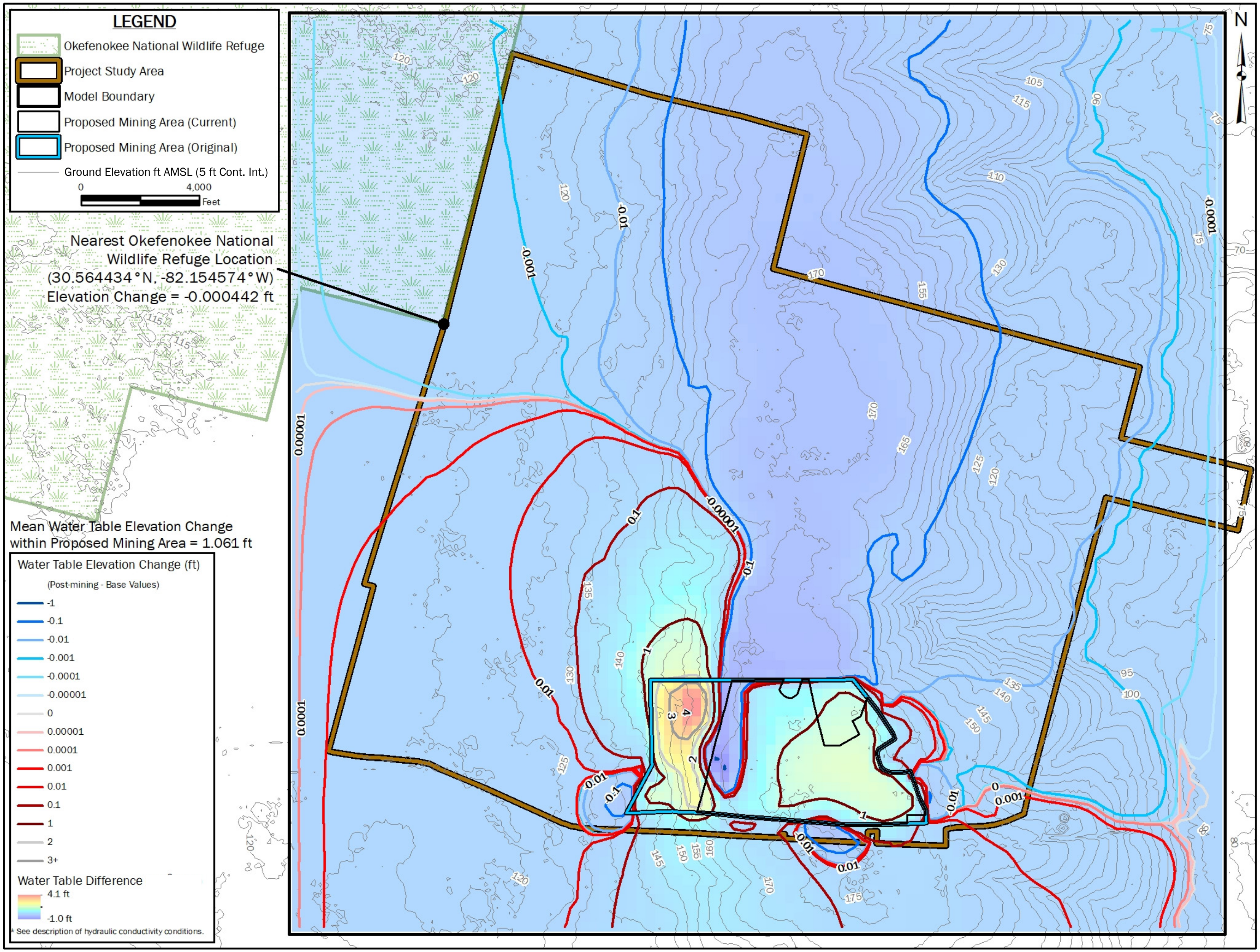

FIGURE 28: HYDRAULIC HEAD DIFFERENCE BETWEEN LAYERED SCENARIO HERE MODELED HERE & PRE-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-06 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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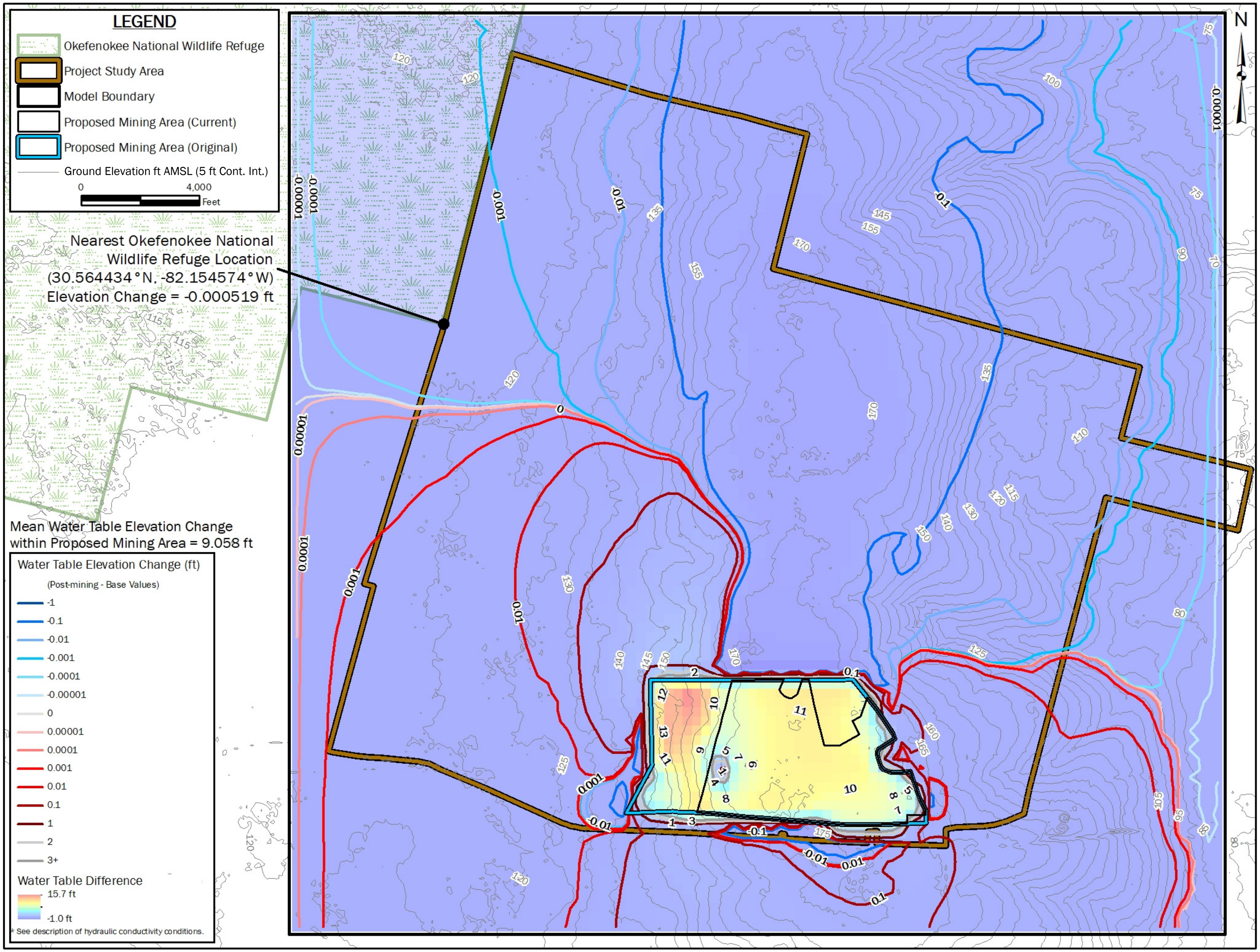

FIGURE 29: HYDRAULIC HEAD DIFFERENCE BETWEEN LAYERED SCENARIO HERE MODELED HERE & PRE-MINING SCENARIO OF HOLT ET AL. (2020); THE VERTICAL EFFECTIVE K OF THE UPPER 10 FEET OF THE MINE FOOTPRINT IS 1E-07 CM/S & THE HORIZONTAL K IS 1E-03 CM/S

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